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The comparative calcium and phosphorus retention of pigs fed rations supplemented with limestone, bone meal, and "Dicapho"

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THE COMPARATIVE CALCIUM AND PHOSPHORUS RETENTION OF PIGS FED RATIONS SUPPLEMENTED WITH LIMESTONE, BONE MEAL, AND "DICAPHO"

By

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TABLE OF CONTENTS

INTRODUCTION

Grains and their by-products form the greatest part of the ration for swine, a fact based upon economic as well as physiological principles. A knowledge of the nutritive deficiencies of these feeds and means by which these deficiencies may be corrected is of great importance in the swine industry.

It has long been known that grains and their by-products do not contain sufficient minerals for normal nutrition, particularly in regard to growth, pregnancy, and lactation. Of the eleven mineral elements (Ca., Mg., Na., K., P., S., Cl., I., Fe., Cu., and Mn.) which, according to the present status of our knowledge of nutrition, are known to be necessary, those required in the largest amount during the life of the animal are calcium and phosphorus. Phosphorus usually predominates in grains and their by-products, while the calcium content of grains is generally very low. Since calcium is present in the skeleton and in milk in larger quantities than any other inorganic constituent and, since it is indispensible to the normal functioning of the soft tissues, it is most important that a sufficient amount of this element be present in the ration.

Efforts have been made to overcome the calcium deficiency in grains by the use of feeds and minerals that are rich in this element. When organic and inorganic calcium compounds are used as supplements to the grain ration of the pig, the question naturally arises concerning the comparative metabolic utilization of these calcium supplements. The data reported in this thesis, therefore, are an attempt to contribute to our knowledge on this question.

STATEMENT OF PROBLEM

Iowa farmers annually buy large amounts of organic and inorganic calcium compounds to supplement hog rations. Limestone and bone meal are most widely used as calcium supplements, while Dicapho (commercial dicalcium phosphate) is used to a more limited extent. These three calcium compounds vary greatly in cost, and this research was instituted to determine if, under certain conditions, the difference in metabolic utilization of these calcium salts was great enough to justify the difference in cost to the farmer.

REVIEW OF LITERATURE

A. The Function of Calcium and Phosphorus in Nutrition

Sherman (82) states that about 85 per cent of the mineral matter of bone and at least three-fourths of the ash of the animal body consist of calcium phosphate. Approximately 99 per cent of the calcium in the body is found in the bones, and the remainder is an essential constituent of the soft tissues and body fluids. Calcium salts are essential for the normal process of blood coagulation and for the contraction of the heart (45).

According to Orr (67), calcium is present in every normal cell; moreover, its presence at a constant concentration is necessary to the normal functioning of every cell in the animal body. There is considerable evidence (21), (25), (92), to show that the skeleton acts not only as a framework for the body but also as a reserve supply of calcium which may be utilized to supplement the food calcium when there is an insufficient amount in the diet to meet the requirements of the animal. For example, a fast growing animal which is not provided with sufficient food calcium to meet the requirements of the soft tissues and fluids, draws upon the calcium already stored in the bones (18), (30). It is also a known fact that a cow, when lactating heavily, has a negative calcium balance (37), (65). According to Ellenberger (24), negative calcium balances are normal in the early part of the lactation period, but they are followed by rapid storage of calcium as the lactation and gestation periods progress.

Phosphorus compounds are widely distributed in the body and form an integral part of every living cell. Sherman (82) presents the following general classification of phosphorus compounds as related to nutrition:

> 1. Inorganic phosphates, of which potassium phosphate is probably the most abundant in food and in the fluids and soft tissues of the body, while calcium phosphate is the chief inorganic constituent of bones.
>
> 2. Phosphorus-containing proteins, including the nucleo-proteins of cell nuclei, the lecitho-proteins, and the true phospho-proteins such as casein or caseinogen of milk and ovovitellin of egg yolk.
>
> 3. Phosphatids, phospholipins, or phosphorized fats — including lecithins, lecithans, kephalins, etc. — which occur in large quantity in brain and nerve tissue and in smaller concentration (but probably as essential components) in all the cells and tissues of the body, not only of man, but of plants and animals generally. The phosphatids are therefore widely distributed in food materials, but are found in extremely varying proportions in foods of different types. Egg yolks are conspicuously rich in phosphatids, about two-thirds of the phosphorus of the egg being present in this form.
>
> 4. Phosphoric acid esters of carbohydrates and related substances such as inosital (inosite) and the natural salts of such esters. The calcium, magnesium, and potassium salts of phytic acid, collectively known as phytates, phytins, or phytin have for some years been regarded as the most abundant phosphorus compounds of the wheat kernel and probably of the grains and legumes generally, if not of all the vegetable foods.

Forbes and Keith (28) make the following comments on the phosphorus metabolism of the animal:

> Among the several inorganic elements involved in animal life, phosphorus is of special interest. No other one enters into such a diversity of compounds and plays an important part in so many functions. Structurally it is important as a constituent of every cell nucleus, and so of all cellular structures; it is also prominent in the skeleton, in milk, in sexual elements, glandular tissue and the nervous system. Functionally, it is in-

> volved in all cell multiplication in the activation and control of enzyme actions, in the maintenance of neutrality in the organism, in the conduct of nerve stimuli, and through its relation to osmotic pressure, surface tension and imbibition of water by colloids, it has to do with the movement of liquids, with the maintenance of proper liquid contents of the tissues, with the cell movements and with absorption and secretion.

B. Absorption and Excretion of Calcium and Phosphorus

Calcium exists in feeds in both organic and inorganic combinations. According to Hunter (48), it is probable that the digestive juices convert it entirely into the inorganic form so that it is absorbed as calcium salts partly or completely ionized. Stewart and Percival (90) state that the absorption of calcium is governed by two main factors, vitamin D and intestinal pH. It is known that lactose stimulates calcium absorption (8), (75), while an excess of certain salts, especially phosphates, are definitely detrimental to calcium absorption (50), (73), (81). It is generally accepted (90), (93) that calcium is eliminated by the large intestine and to a lesser extent by the kidney. In the pig the excretion by way of the urine varies from one to 20 per cent of the total outgo with an average value of approximately five per cent (29), (32), (73).

Upon the ingestion of feeds with their variety of organic and inorganic phosphorus compounds, the same process of simplification and absorption begins, which process is general for other groups of the nutrient components of the feeds (28). The inorganic phosphates are absorbed as such, while the organic phosphorus compounds are broken down into more simple constituents before absorption. The absorption of phosphorus, like calcium, is influenced by other factors including the amount of calcium in the diet (12), (51), (73).

Phosphorus is excreted by way of the urinary tract to a much greater extent in the pig than is calcium. There are exceptions however; when a pig receives calcium carbonate as a supplement to its ration the excretion of phosphorus by way of the kidney diminishes to amounts much lower than the normal excretion of calcium in the urine (29), (36), (81). The urinary elimination of phosphorus in the pig is approximately 25 per cent of the total outgo of phosphorus in the feces and urine, but values have been reported varying from one to 50 per cent.

C. Factors Affecting Calcium and Phosphorus Metabolism

1. Calcium and Phosphorus Ratio

The importance of the calcium to phosphorus relationship in diets is borne out in results obtained when rations are fed wherein one or the other of these elements is greatly in excess of the other (73), (94).

Bethke (10) states that, within certain limits, the proportion of calcium to phosphorus in the diet is of greater significance in calcification than the amount of the respective elements in the ration. McCollum and associates (63) report data in accord with this viewpoint. In studying the effect of the various levels and ratios of calcium to phosphorus in the diet upon the production of rickets in rats, Brown and co-workers (19) report that as the ratio of calcium to phosphorus in the diet increases, rickets is intensified. They also state that as the level of the minerals is increased in the diet, the incidence of rickets diminishes. A number of investigators (13), (51), (73), (84) have demonstrated the beneficial effect of adding phosphate to a high-calcium low-phosphorus rachitic ration, thus correcting the wide Ca:P ratio.

Orr and associates (69), in an experiment with humans, report that the absorption of calcium and phosphorus does not always run parallel. They found that a high phosphorus intake increased the calcium in the stools and decreased the calcium in the urine, while a high calcium intake increased the phosphorus in the stools and decreased the phosphorus in the urine. Their explanation is quite logical:

> It would appear that an excess of either calcium or phosphorus in the diet tends to increase the output of the other element in the intestine, and the natural assumption that has been made is that this is due to the precipitation of insoluble phosphates of calcium in the intestine. Apparently only calcium ions, the various types of phosphate ions and molecular phosphates of calcium in solution can pass through the intestinal mucosa, but insoluble phosphates of calcium cannot be absorbed.

Orr's conclusions are supported by experiments carried on by other investigators (51), (73). It would seem therefore, that for maximum retention of both elements, neither calcium nor phosphorus should be greatly in excess of each other in the diet.

Kramer and Howland (56) report on factors influencing the ratio of calcium and inorganic phosphorus in the blood. A Ca:P ratio of 1.5:1 in the rat's diet gave the same ratio in the blood serum irrespective of the amount of vitamin D in the diet. With minimum amounts of vitamin D present in the diet an increase in the intake of calcium raised the serum calcium and depressed the serum phosphorus. The opposite effect was produced when the phosphorus intake was increased. As the concentration of vitamin D was increased in a diet with a wide Ca:P ratio, the blood serum relationship of these elements approached normality. In the blood of the pig the normal Ca:P ratio is reported to be 1.4:1 (46) with the calcium content of the blood serum being slightly in excess of 12 milligrams per 100 cubic centimetres of blood, and the inorganic phosphorus content between eight and nine milligrams.

Regarding the correct calcium-phosphorus relationship in the pig's diet, very few definite recommendations have been made. Bartels (5) reports that the calcium and phosphorus content of sow's milk is 0.28 per cent and 0.16 per cent respectively. According to these values the Ca:P ratio of sow's milk is 1.75:1. The same investigator found that suckling pigs retained 1.08 grams of calcium and 0.59 grams of phosphorus per day. The retention ratio was 1.83:1. This is in accord with other published data (85).

Following the suckling period the calcium and phosphorus retention ratios are more subject to variation depending largely on the amount and ratio of calcium to phosphorus in the diet. Bethke (10) states that the most favorable calcium-phosphorus relationship in the pig's diet lies between 1:1 and 2:1. The requirements for the antirachitic factor are at a minimum at this relationship.

Gloy (32) recommends a Ca:P ratio of 1.09:1 in the ration of the growing pig. After extensive metabolism studies with hogs, Reimers and Smuts (73) found that a calcium (CaO) to phosphorus (P_2O_5) relationship in the diet of 1.2:1 or 1.98:1 when expressed as elemental calcium and phosphorus, gave the best results. On the basis of calcium and phosphorus intake advised by Orr (68), the ratio would be 1.6:1. It is interesting to notice the similarity of the recommended dietary calcium-phosphorus relationship of the pig to that of other omnivorous species; for example, the rat and human. McCollum (62), Bethke (9) and Blum (14) agree that the most desirable Ca:P ratio for the rat is between 2:1 and 1:1.

Blunt and Cowan (15) have published data summarizing the results of different investigators on the dietary calcium-phosphorus relationship of children in health and in disease. These data indicate that a dietary ratio of 1.4:1 may be considered optimum.

2. Vitamin D and Ultra-violet Light

Our present knowledge of the relationship of ultra-violet light and vitamin D to calcium and phosphorus metabolism traces back to the experiments of Huldschinsky (47), who demonstrated the value of ultra-violet light in the treatment of rickets in children, and to the research of McCollum and associates (62), who discovered vitamin D and demonstrated its value in the therapy and prevention of rickets in animals. For a few years following these important discoveries, the relationship between vitamin D and ultra-violet light was not understood. Experiments were reported almost simultaneously by Hess and Weinstock (41), and Steenbock and Black (87). These experiments showed that ultra-violet irradiation induced antirachitic properties in foods. Later, Hess and Windaus (42) reported that it was the ergosterol in food which became activated upon ultra-violet irradiation. It is now generally accepted that vitamin D is formed by the action of ultra-violet light on ergosterol.

Brown and Shohl (18) have studied the effect of increased dosage of irradiated ergosterol on calcium and phosphorus metabolism. They added increasing amounts of ergosterol and noted that, up to a certain point, the bone ash became heavier and the calcium retention greater. With larger doses there was a shift of calcium excretion from the feces to the urine and a low or negative calcium balance with pathological calcification taking place in the tissues. They conclude that vitamin D controls calcification of the skeleton by dissolution and deposition of the bone salts. Hess and co-workers (40) have published data which support the above conclusion. They fed dogs a ration absolutely free of calcium and were able to induce at the same time hypercalcemia by including large amounts of irradiated ergosterol in the diet.

Bauer and Marble (6) report that when cats, which had been receiving a complete diet, were changed to one low in calcium, the number of bone trabeculae decreased, whereupon supplemental calcium was given and the number of bone trabeculae increased. A still greater increase was secured when irradiated ergosterol was included in the diet. They conclude that the trabeculae can store calcium and give it back to the blood stream as demanded.

Many experiments (58), (59), (71), (79), (81), (86), (89),

(97) have been conducted with pigs to study the value of vitamin D and ultra-violet light in the prevention and cure of rickets. In each experiment the use of antirachitic, whether it was in the form of cod-liver oil, ergosterol, sunlight, or artificial ultra-violet light, proved successful. The rations fed in these experiments ranged from those which were deficient in calcium content to rations which were apparently quite normal in calcium content. It has been shown that pigs develop rickets when fed rations dificient in both calcium and the antirachitic factor, but when the antirachitic factor was included in the ration, the pigs did not show any noticable effects of mal-nutrition; however, a chemical analysis indicated that the calcification of the bones was not as great as when calcium was supplied in sufficient amounts (59), (86). Zilva and co-workers (97) report that pigs develop rickets when fed a ration deficient in vitamin D. The ration fed contained 22 grams of calcium and 13 grams of phosphorus, making the Ca:P ratio 1.7:1, which is not considered conducive to the production of rickets. It appears therefore that, even though calcium and phosphorus are present in the ration in favorable amounts, rickets may develop if the ration is deficient in vitamin D. There may be some question as to the sufficiency of vitamin A in the diets used by Zilva.

Shaw (79) found that pigs which had been grown on a complete ration up to four months of age were much less susceptible to rickets than those subjected to experimental treatment at two months of age. According to Maynard (59) and Sheehy (81), rickets may be prevented or alleviated when the animal is exposed to direct rays of winter sunlight. Both authorities, however, found that exposure to summer sunlight was more effective because greater amounts of ultra-violet rays reach the earth at this season of the year. In this regard Tisdall and Brown (91) report that the intensity of ultra-violet irradiation from the sun in these latitudes (Toronto) is eight times greater in summer than in winter.

3. Acid-Base Balance

Data on the effect of the acid-base balance on calcium and phosphorus retention are rather contradictory, although most of the evidence indicates that a potentially neutral diet is most desirable. Shohl and co-workers (84) varied the potential acidity of the Steenbock rachitic ration by adding different phosphates. Rickets was cured in every case. The retention of calcium and phosphorus was greatest when the diet was neutral and least when it was potentially acidic. The alkaline diet was intermediate in this respect. The milligrams per cent of calcium and inorganic phosphorus in the blood serum was in agreement with retention values of calcium and phosphorus.

Petersen's researches (72) indicated that when conditions were favorable to high calcium and phosphorus retention in pigs, the sum of the free acid and ammonia in the urine was small. He recommends, therefore, the use of calcium carbonate as a calcium supplement to a ration composed largely of cereals (potentially acid), and calcium chloride as a desirable supplement for rations potentially basic. Bartels' (5) experiments with pigs are in agreement with this view.

Salter (78) and his co-workers were unable to demonstrate that potential acidity had any definite influence upon the absorption and retention of inorganic phosphorus. Moreover, the daily addition of 200 to 300 cubic centimetres of normal sulphuric acid to a complete ration for young brood sows produced no noticable effect on growth, reproduction, or bone composition according to Lamb and Evvard (57). On the other hand, Shohl (83) states that acid diminishes the positive balance of minerals, while alkali increases the positive base balance.

4. Thyroid-Parathyroid Hormones

There is no longer any reason to doubt that the secretion of the parathyroid gland is associated with calcium metabolism. Numerous investigators (1), (7), (22), (49) have demonstrated that the physiological changes which occur during hyperparathyroidism, or when parathorome is administered, are an increase in blood calcium, hypercalcemia, increased urinary calcium and phosphorus, and depletion of the calcium stores of the bone. Bauer (7) found that bone trabeculae which, according to the same author, serve as a reserve of calcium, are reduced in number following injections of parathorome over long periods. Collip (22), by the use of parathorome, cured parathyroid tetany in dogs. He observed that the blood calcium, which was subnormal, returned to a normal level. Moreover, he increased the serum calcium above normal upon injecting parathorome into normal animals.

Aub and associates (4) have published experimental data which indicate that the thyroid gland also plays a part in calcium metabolism. A study of patients with a wide range of thyroid diseases showed that increased thyroid secretion caused a marked increase in calcium excretion. Similar results were observed in a normal individual following the administration of thyroxin. On the other hand, the calcium excretion of patients suffering with myxedema was lower than normal. X-ray evidence indicated that marked osteoporosis may develop in bones from prolonged hyperthyroidism. Hammett (34) states that the ossification ability of the bones is greatly decreased upon thyroid-parathyroidectomy.

D. The Calcium and Phosphorus Requirements of the Pig

While calcium and phosphorus are necessary in the diet in adequate amounts at all times for normal calcium and phosphorus metabolism, the demand is much greater during growth, pregnancy, and lactation than in maintenance. Recommendations regarding the calcium and phosphorus requirements of the pig, therefore, must be interpreted with these facts in mind. Kellner (53) recommends that the growing pig should receive 12 grams each of lime (CaO) and phosphoric acid (P_2O_5) which, expressed as elemental calcium and phosphorus, amounts to 8.6 grams of calcium and 5.2 grams of phosphorus.

Hart and co-workers (35) report that three grams of elemental phosphorus daily is a minimum supply for a growing pig weighing 50 pounds, and that four to five grams would be a safer quantity. Orr (68) states that calcium and phosphorus constitute one-half the weight of bones. When the whole animal is considered, lime (CaO) is present in the body of store pigs to the extent of one per cent and phosphorus (P_2O_5) is present in slightly less amounts. The hog therefore, for every hundred pounds increase in weight throughout the period of growth, requires one pound each of these minerals as constructive material. Orr states that in estimating the amounts of calcium and phosphorus required, it must be kept in mind that only a percentage of what is eaten is absorbed and retained. To cover the loss through failure to assimilate all that is present in the feed and the loss in excreta of part of what has been assimilated, the young growing animal needs to receive twice that required for constructive purposes. On this basis, a pig making one pound gain in weight per day would require more than one-third of an ounce (9.3 grams) of each mineral in the daily ration. These values expressed as elemental calcium and phosphorus amount to 6.6 grams of calcium and 4.1 grams of phosphorus.

Gloy (32), after donducting many metabolism experiments, states that 20 grams of calcium oxide (14.1 grams Ca.) and 30 grams of phosphorus pentoxide (13.1 grams P.) may be considered optimum amounts in the ration of growing pigs.

Extensive study by Reimers and Smuts (73) showed that the growing and fattening pig had a maximum calcium retention of between nine and ten grams per day and a maximum phosphorus retention of five to six grams. These values were obtained when the pigs were receiving approximately 30 and 19 grams of calcium and phosphorus respectively per day.

Weiser and Zaitschek (94) have published data which indicate that the percentage of calcium and phosphorus in the pig's ration is most likely to be deficient early in the growth period. They found that the retention of calcium and phosphorus per 100 kilograms liveweight decreased at a rapid rate during the period studied (16 to 28 weeks). The rate of retention of pigs 28 weeks old was less than one-third of the retention rate of pigs 16 weeks of age.

Steenbock and Hart (88) report that the level of calcium necessary for maintenance of the pig depends upon the functional activity of the various organs of the body. A daily intake of 0.3 grams of calcium oxide (0.21 grams Ca.) per 100 pounds liveweight covered the metabolism losses of a mature barren pig.

Hogan (43) was able to produce gilts on rations that contained as little as 0.2 per cent calcium. Later, these pigs weaned litters successfully without increasing the calcium intake. Other gilts did not do so well, so he estimates that a reasonable regard for safety would require that the rations of brood sows contain not less than 0.4 per cent calcium. His experiments show that a ration which contains sufficient calcium for growth also furnishes sufficient of this element for pregnancy and lactation.

Evans (26), by slaughtering a sow which had lived on a normal diet and had just completed rearing 12 pigs to weaning age, found that the skeleton was quite similar in composition to the skeleton of non-lactating sows, indicating that 16.6 grams of calcium supplied in her diet had been sufficient to meet the requirements of lactation and body maintenance. The same investigator (25) reports balance experiments in which pregnant sows have attained lime equilibrium on less than two grams of calcium oxide (1.4 grams Ca.) intake per day.

Davidson (23) states that a ration deficient in calcium does not produce an immediate effect upon breeding sows. Experimental results indicate that the effects of deficiency require two to three generations to become pronounced, due to the sow's ability to store lime following the lactation period. The continued use of a calcium deficient ration leads to a very serious reduction and eventual failure of the sow's milk supply as well as a marked increase in the number of still-born pigs.

E. The Distribution of Calcium and Phosphorus in Feeding Stuffs

Feeding stuffs vary greatly in calcium and phosphorus content. Cereals, which comprise the largest percentage of the diet for hogs, contain insufficient calcium to supply the demands for growth, reproduction, and lactation. On the other hand, cereals and their by-products contain phosphorus in comparatively large amounts, and in most instances there is sufficient phosphorus in cereals to meet the demand for this element. For example, corn contains over twenty times as much phosphorus as calcium. It is evident, therefore, that calcium must be added to equalize the intake of these elements where corn forms the greatest part of the ration.

Data on the per cent of calcium and phosphorus in feeds, and the amounts of these feeds necessary to provide a growing pig (75 to 150 pounds) with a daily calcium and phosphorus intake of ten and seven grams respectively, are tabulated in the following table. The values for the daily intake of calcium and phosphorus are averages of data (5), (32), (68), (73), (81). (See p.23 for table.)

An examination of the table shows that all seeds listed, as well as their by-products, contain much greater amounts of phosphorus than calcium. Roots and tubers, for the most part, contain calcium and phosphorus in more suitable proportions, but even on a moisture free basis they contain very small amounts of these elements. Most forage crops and animal by-products contain more calcium than phosphorus; therefore, by using suitable proportions of the above feeds, it is possible to construct rations for the hog satisfactory in calcium and phosphorus content without adding mineral supplements. This is demonstrated in the data reported in this thesis where a ration composed of ground corn, tankage, linseed oilmeal, alfalfa meal, and salt (NaCl) gave excellent results. It is often more economical and practical to add a mineral supplement to meet the mineral needs than to balance the calcium and phosphorus in the ration with feeding stuffs.

As early as 1842 Chossat (21) demonstrated the value of inorganic salts in supplementing cereals. He fed pigeons on wheat only and the birds died from mal-nutrition in eight to ten months. The salts were gradually withdrawn from their bones and the breast bone became very porous. When wheat was supplemented with calcium

Calcium and Phosphorus in Representative Feeding Stuffs

Feed	Percentage of Ca. and P. on a dry matter basis (28)		Percentage of moisture (39)	Amt. of feed required to supply 10 gms. Ca. per day	Amt. of feed required to supply 7 gms. P. per day
	Ca.	P.	%	Lbs.	Lbs.
Barley	0.043	0.400	9	56.4	4.2
Corn	0.014	0.303	12	179.2	5.8
Oats	0.112	0.434	9	21.6	3.9
Rye	0.055	0.385	9	44.1	4.4
Wheat	0.056	0.425	10	43.7	4.0
Soybeans	0.230	0.649	10	10.7	2.6
Soybean oilmeal	0.355	0.733	10	6.9	2.3
Linseed oilmeal	0.403	0.786	9	6.0	2.2
Cottonseed oilmeal	0.291	1.479	8	8.2	1.1
Wheat bran	0.139	1.233	10	17.6	1.4
Wheat middlings	0.108	0.984	10	22.7	1.7
Pearl hominy	0.005	0.111	10	489.9	1.5
Gluten feed	0.268	0.589	9	9.0	2.9
Distillers' Grains (corn)	0.047	0.314	7	50.4	5.3
Brewers' Grains	0.169	0.503	8	14.2	3.3
Turnips	0.064	0.046	90	344.5	335.5
Mangels	0.131	0.260	90	168.3	59.4
White Potatoes	0.070	0.276	79	150.0	26.6
Sweet Potatoes	0.084	0.186	69	84.8	26.7
Blue grass	0.336	0.242	68	20.5	19.9
Alfalfa meal or hay	1.130	0.238	9	2.1	7.1
Soluble blood flour	0.028	0.135	10	87.5	12.7
Tankage 7% Ca.	7.543	3.739	8	0.3	0.4
Skim milk (Cow)	1.336	0.979	90	16.5	15.8
Sow's milk	0.969	0.729	81	12.0	11.1

carbonate, pigeons did not show these symptoms and appeared to be in normal health. The significance of this discovery was not realized at that time. Doubt remained as to the usefulness of inorganic salts in supplementing cereals until 1908 when Aron and Frese (2) proved that tertiary calcium phosphate was just as useful as a source of calcium for growing dogs as was milk.

F. The Comparative Efficacy of Minerals as Calcium Supplements to Rations for Growing Pigs

Weiske (95) was perhaps one of the first investigators to study the differences in the metabolic utilization of calcium salts. In 1895 he reported on the value of calcium carbonate and calcium sulphate as supplements to an oat diet for rabbits. The carbonate proved to be somewhat better as judged by the percentage of bone ash. Forbes and co-workers (29), in extensive experiments on the utilization of various calcium compounds by swine, found that there was little difference between pulverized limestone, precipitated calcium carbonate, precipitated bone flour, and steamed bone flour, while rock phosphate was quite inferior to the other supplements as a source of calcium. McClure and Mitchell (61) state that when rock phosphate contains two per cent or more of fluorine, the growth, feed consumption, and calcium metabolism of the pigs are depressed. Metabolism experiments conducted by Sheehy and Senior (81) indicate that calcium carbonate is more efficiently utilized by hogs than is bone meal, although the investigators are of the opinion that the difference is insignificant. Hart and associates (36) compared calcium carbonate with tricalcium phosphate as calcium supplements in pig rations. Calcium carbonate was superior, and they attributed the superiority to a better balance of calcium and phosphorus in the ration. After extensive experimentation, Petersen (70) stated that limestone, chalk, and pure calcium carbonate were equal in their calcium supplementing efficiency for hogs. Data are also reported (31) showing little difference in the utilization of calcium carbonate and sulphate by pigs. Gloy (32) compared calcium carbonate and calcium chloride as calcium supplements to rations for growing and fattening pigs, and the calcium and phosphorus retention values showed that the carbonate was superior to the chloride. On the other hand, Kleisch (54) reported no difference in the value of these salts as calcium supplements for hog rations. After conducting many metabolism experiments, Bartels (5) concluded that the comparative value of calcium carbonate, chloride, and phosphate, as supplements to hog rations, depended upon the acid-base balance of the basal ration. Calcium carbonate was recommended as a supplement to a potentially acid ration, and calcium chloride or phosphate as supplements to a potentially basic ration.

A review of the literature relating to calcium supplements for hog rations indicates that little experimental work has been conducted in which dicalcium phosphate or "Dicapho" (commercial dicalcium phosphate) has been compared with other calcium compounds. In this regard, Bohstedt (17) reports that a limited amount of data indicate that dicalcium phosphate is superior to tricalcium phosphate for hogs. When Dicapho was compared with other calcium salts (calcium carbonate and tricalcium phosphate) as a calcium supplement to rations for growing rats, it was utilized to a greater extent, as indicated by calcium and phosphorus retention values and roentgenographic studies on the bones (13). On the other hand, Köhler (55) and Honcamp (44) found that lambs utilized di- and tricalcium phosphates to a similar degree. Both of these salts, when used as calcium and phosphorus supplements for lambs, were utilized to a greater extent than steamed bone meal or bone ash, as indicated by growth and calcium and phosphorus retention values. Data are reported which indicate dicalcium phosphate, steamed bone meal, and limestone to be equal as calcium supplements for growing chicks (11), (20).

In view of the fact that Dicapho is being used in considerable quantities as a calcium supplement in hog rations, and since little information is available on its utilization by hogs as compared to limestone or bone meal utilization, it is believed that information on this question should prove to be of fundamental importance and immediate practical value.

EXPERIMENTAL

Part I: Metabolism Experiment

A. Object of Experiment

This experiment was undertaken to obtain information on, and to compare, the calcium and phosphorus retention of growing pigs fed ground limestone, steamed bone meal, and Dicapho as supplements to certain rations.

B. Method of Experimentation

1. Outline of Experimental Procedure

Data have been collected in metabolism experimentation, which involved 15 growing pigs ranging from 50 to 230 pounds in weight. Four metabolism trials were conducted, each of which consisted of two to five experimental periods 10 or 14 days in length. A series of consecutive tests made on the same group of pigs denotes a trial. Each test in a trial is termed a period and constitutes a specific comparison of rations. The only exception was in the case of the check periods, wherein the pigs were compared in regard to individual variation in calcium and phosphorus metabolism.

Trials I, II, and III were designed to determine the efficacy of ground limestone, steamed bone meal, and Dicapho when fed as calcium supplements to a basal ration deficient in calcium. It was proposed to test the calcium supplements at both low and high levels of supplementation in all trials, but due to complications (which will be discussed later) the tests at high levels of calcium supplementation were not possible in Trials I and II. Trial IV, involving three metabolism periods, was conducted in conjunction with the feed lot experiment reported in Part II to follow. In this trial, limestone, bone meal and Dicapho were used as supplements to a practical ration fed to pigs grown and fattened in dry lot.

2. Animals Used

The animals used in these balance metabolism trials were purebred Poland Chinas with the exception of those used in Trial IV. The breeding of the pigs used in Trial IV was as follows: No.197, purebred Poland China; No. 3014, Poland China-Duroc Jersey cross; No.3018, Poland China-Yorkshire cross; No.3046, Poland China-Duroc Jersey cross. Factors considered in selecting the pigs were: weight, age, condition, and probable outcome. Barrows were selected rather than gilts in order to prevent any possible loss of urine at the doors of the metabolism crates.

When the animals were received at the metabolism laboratory, they were placed in the metabolism crated to accustom them to confinement and the new environment before experimentation. They were treated for internal and external parasites at least once, and more often if necessary, several days before the periods began. All pigs were fed the rations to be compared at least four days prior to the beginning of each experimental period. They were washed thoroughly with soap and water and rinsed with distilled water a few hours preceding each test, and during the periods the pigs were brushed frequently to keep their skin in a healthy condition. Whenever necessary, mineral oil was applied externally to prevent the skin from drying and chafing.

3. Housing and Equipment

The animals were housed in the metabolism room of the animal laboratory, Animal Chemistry and Nutrition Sub-Section. The metabolism room, 22.5 feet by 17.0 feet, was equipped with four metabolism crates and other supplementary equipment. This room had two large windows opening to the north, 7.0 feet by 5.5 feet in size. The temperature was thermostatically controlled and varied very little from 70° F.

The metabolism crates were similar in their structure to those used by Forbes (30). They were somewhat smaller in size however, being 57.5 inches by 39.5 inches (outside measurement). They were fitted with castors allowing them to be moved on a fixed grooved base. These bases, two in number, were each 5.0 feet by 10.5 feet and were divided into three parts. Each part had a galvanized floor which sloped toward the centre. The two outer parts were used as floors for two metabolism crates, and the centre part was an extra floor upon which either crate could be moved while the crate floor was being cleaned or feces collected. The funnel-shaped galvanized floors were equipped with removable heavy galvanized wire screens upon which the pig stood. Two inches below this heavy wire screen, a white sheet, 57.5 inches by 39.5 inches in size, was held in position by a light wire frame. This sheet functioned as a medium to separate the feces and urine, inasmuch as the feces were deposited upon it and the urine filtered through it to the apex of the funnel-shaped base and was collected in four-litre jars placed underneath the crate.

4. Rations and Method of Feeding

The low-calcium basal rations used in Trials I, II, and III were composed of the following feeds: ground yellow corn, soybean oilmeal, blood flour, and salt. These rations contained from 0.05 to 0.10 per cent calcium, depending upon the proportion of the constituents. By using a basal ration extremely low in calcium, it was possible to have the greater part of the calcium in the ration in the form of calcium supplements. In an effort to make conditions more stringent, thereby increasing the possibility of showing differences in the utilization of the calcium compounds, vitamin D additions were purposely omitted from the experimental diets in any concentrated form. The vitamin D supply of the animals therefore, was limited to that acquired before they were brought to the animal laboratory plus possible minimum quantities in the basal ration. The ingredients of the basal ration, when combined, quite adequately supplied all nutrients necessary for growth except calcium and vitamin D. The basal ration fed in Trial IV and in Period I of Trial I was a practical ration composed of ground yellow corn and trinity mixture (tankage 50 per cent, linseed oilmeal 25 per cent, alfalfa meal 25 per cent).

The following table gives the percentage composition of the basal rations used in the metabolism experiment.

TABLE I

Percentage Composition of the Basal Rations

Basal Ration:	A	B	C	C	D	E
Trial:	I	I	II	III	IV	IV
Period:	I	II	I,II	I,II,III,IV	I	II,III
Ingredients						
Corn	85.000	93.5	83.5		80.000	90.000
Tankage	7.250				9.750	4.750
Blood flour		4.0	4.0			
Linseed oilmeal	3.625				4.875	2.375
Soybean oilmeal		2.0	12.0			
Alfalfa meal	3.625				4.875	2.375
Salt (NaCl)	0.500	0.5	0.5		0.500	0.500
Total	100.000	100.0	100.0		100.000	100.000
Nutritive Ratio	1:6	1:7	1:5		1:5	1:7

Each of the above rations were constructed to conform to the recommendations of the Henry and Morrison Feeding Standard (39). The rations, with a nutritive ratio of 1:5, were fed to pigs weighing between 50 and 140 pounds. The rations, with the nutritive ratios of 1:6 and 1:7, were fed to pigs weighing between 140 and 240 pounds.

Notes on the feeds employed in compounding the rations follow:

Corn.

The corn was yellow in color, well matured, and locally grown in 1931. It was ground to a fine meal for the metabolism trials in order that the ration might be mixed thoroughly. This insured accurate sampling. The corn was a desirable constituent in the low-calcium basal ration in that it contained only 0.014 per cent of calcium.

Tankage.

The meat meal tankage contained 60 per cent protein and 20 per cent ash and was manufactured by Swift and Company, Chicago.

Blood Flour.

The blood flour contained 80 per cent protein and was a product of Swift and Company, Chicago. It was used as a constituent of the low-calcium basal ration partly on account of its low calcium content and also because it is satisfactory as an animal protein (80), (96).

Linseed Oilmeal.

The linseed oilmeal contained 36 per cent protein and was manufactured by Archer-Daniels-Midland Company, Minneapolis, Minn.

Soybean Oilmeal.

The soybean oilmeal contained 39 per cent protein. This product, when purchased from the Standard Soybean Mills, Centerville, Iowa, was a coarse meal; therefore, it was necessary to grind it to a fine meal for the metabolism work. It was used as a constituent of the low-calcium basal ration on account of its protein supplementing efficiency and low calcium content (76).

Alfalfa Meal.

The alfalfa meal (XXX Brand) was a product of the Denver Alfalfa Products Company, Le Mar, Colorado.

Salt.

The salt was 98 per cent sodium chloride and a finely pulverized product. It was manufactured by the Morton Salt Company, Chicago.

Limestone.

The limestone was a high grade calcium carbonate limestone prepared by the Michigan Limestone and Chemical Company, Buffalo, New York. It contained 97 per cent calcium carbonate, 38.0 per cent calcium and 0.0 per cent phosphorus. As purchased, the limestone would not all pass through an 80-mesh per inch wire sieve. This material was reground and resifted, and only that which would pass through a 200-mesh per inch sieve was used for metabolism work, with the exception of Trial IV where the limestone was used as purchased.

Steamed Bone Meal.

Swift's special steamed bone meal was used. It was manufactured by Swift and Company, Chicago, and contained 53.0 per cent ash, 33.0 per cent calcium, and 16.2 per cent phosphorus. As purchased it was not all ground finely enough to pass through a 40-mesh per inch sieve. This product was reground and resifted for the metabolism experiment and only that which would pass through a 200-mesh per inch sieve was used. In Trial IV and in the feeding experiment, the steamed bone meal was used as purchased.

Dicapho.

Dicapho is a trade name for a brand of precipitated dicalcium phosphate produced by the Bay Chemical Company, New Orleans, Louisiana. It contained 97 per cent $Ca_2H_2(PO_4)_2H_2O$, 28.5 per cent calcium and 21.4 per cent phosphorus. Dicapho is manufactured by treating rock phosphate with sulphuric acid, and the resulting products are "Dicapho," and Salt Cake (Na_2SO_4). As purchased, the Dicapho would pass through a 200-mesh sieve, so it was not sifted except where it was necessary to break down coalesced particles.

The constituents of all rations were mixed thoroughly in the form of a fine meal by a large mechanical rotary feed mixer (MacLellan Batch Mixer) before experimentation. Preceding each period, a small rotary feed mixer of the same make was used to mix the supplemental compounds with the basal ration. The prepared rations were then weighed on a torsion balance to the nearest tenth of a gram in the desired quantities to be given to the pig at each feeding (twice daily, 8:00 A.M. and 5:00 P.M.) during the period. These weighed portions were sacked in manilla bags which were then sealed and stored in large galvanized cans. The rations were carefully sampled for chemical analysis at this time. The sample taken was approximately one quart of each ration.

The pigs were placed on the experimental ration immediately upon their arrival at the animal laboratory in an effort to reduce residual effects of previous rations. In all cases they were fed the experimental ration four or more days preceding the beginning of the period. The pigs were fed slightly limited rations in all experiments so that they would maintain keen appetites throughout the metabolism periods, thereby reducing waste.

The ration was fed moistened with distilled water and, following each meal, the pigs were given all the distilled water they would drink.

5. Collection, Preservation and Sampling Excreta for Analysis

During each metabolism period the feces were deposited on white cotton sheets, supported on a light weight wire frame, approximately two inches below the removable galvanized wire floor of the crates. Even though the pigs were fed limited rations in specially designed feed hoppers, some feed particles spilled on the sheets near the hoppers. This waste, while seldom great, was carefully returned to the feed trough daily, and every precaution was taken to minimize waste of feed.

In an effort to reduce the experimental error caused by difference in rate of digestion in pigs as it affects collection of feces, carmine, in amounts varying from 0.5 to 1.0 gram, was mixed with the first feed of each pig at the beginning of each metabolism period. The amount of carmine used depended upon the size of the pig and the amount of feed being fed. Collection of feces began with the first carmine colored excreta and collections were made daily, before the morning feeding, during the experimental period. Carmine was again mixed in the first feed following the termination of the period and as soon as the colored feces appeared, collection was terminated.

The total feces excreted by each pig during each period were stored in large glazed earthenware jars. The feces were preserved in a distilled water solution containing 0.2 per cent formalin.

At the end of each experimental period the composite of preserved and finely macerated feces was mixed thoroughly by the use of a large pestle. This feces solution of thick consistency was weighed to the nearest ounce. It was again stirred to insure uniform consistency and a quart sample taken. This sample was pebble-milled for a period of 10 hours in a ball mill which consisted of a four-litre porcelain jar and 7.5 pounds of porcelain balls or flint pebbles. Having been thoroughly milled, the sample was transferred to a glass jar, sealed air-tight, and held for chemical analysis. It contained sufficient preservative to prevent deterioration for one month or longer.

As each pig urinated, the urine filtered through the sheet on to the funnel-shaped galvanized bottom of the metabolism crate. After gravitating to the apex of the funnel, which was fitted daily with an absorbent cotton plug saturated with thymol-chloroform, it was collected in four-litre glass jars placed under each metabolism crate. Approximately two cubic centimetres of thymol-chloroform and five cubic centimetres of hydrochloric acid were used as preservatives per litre of urine. The urine was transferred daily during each period from the collection jars to 50-litre glass carboys. Then, at the end of each period, the surface of the funnel-shaped base of the metabolism crate, which conducted the urine to the collection jars, was scrubbed and then washed with a weak acid solution and distilled water. The sheets which acted as mediums for the collection of the feces were first cleaned free of feces, then washed thoroughly in a solution of distilled water and hydrochloric acid. The purpose of adding the acid was to insure solution of urinary salts. The wash water so collected was filtered into the period collection of urine for each pig. The total urine and wash water collected from each pig during the experimental period was weighed to the nearest ounce, mixed by thoroughly agitating the partly filled carboy, and sampled for chemical analysis. Each sample taken amounted to approximately four litres, which was stored in air-tight brown bottles.

6. Methods of Chemical Analysis

The Calcium in the feed, feces, and urine was determined by McCrudden's Method (64), using the gravimetric alternative. The phosphorus in the ration and excreta was determined gravimetrically by the standard molybdate magnesium mixture method (3). All chemical analyses were conducted in triplicate.

The feed was thoroughly mixed and samples were weighed out to the nearest tenth of a milligram. The feces were uniformly mixed in the sample jars, and approximately 200 grams were transferred to a weighing bottle. From this bottle the individual samples, for analysis, were weighed by difference to the nearest tenth of a milligram. The urine was shaken in the storage bottles until it was homogeneous and then sampled in 50 and 250 cubic centimetre amounts for phosphorus and calcium analysis respectively. The smaller samples were taken with a pipette and the larger ones in a volumetric flask. These samples were evaporated to dryness in evaporating dishes over a steam hot-plate.

Following dehydration the samples were charred over an open flame. At this point in the procedure, the samples for calcium analysis were placed in a muffled furnace and ashed at a temperature of approximately 700° C. The samples for phosphorus analysis were carefully pulverized with a pestle and then treated with ten cubic centimetres of magnesium nitrate solution made according to the A.O.A.C. method (3) The purpose in adding the magnesium nitrate solution was to insure against phosphorus volatilization. The charred urine and magnesium nitrate was dehydrated over a steam hot-plate and then the sample was carefully heated on an electric hot-plate until it burned to a grey color. The ashing process of the samples for phosphorus analysis was completed at a dull red heat in a muffled furnace.

The ash so prepared for the calcium and phosphorus determinations, was dissolved in a mixture of equal parts of hydrochloric acid and distilled water, then dehydrated over a steam hot-plate. The purpose in dehydrating was to precipitate any silica present. The dehydrated ash samples were dissolved in dilute hydrochloric acid, and calcium and phosphorus analyses were made by methods already mentioned.

The procedure for ashing the feed and feces was the same as that employed with the urine following the evaporation. There was one exception, however: The samples for calcium determination were ashed at a dull red heat rather than at a lower temperature, since the ash of the feces and feed was not as susceptible to fusing as the urine ash.

C. Experimental Results

1. Trial I

Period I. Check Ration

Period I was instituted to obtain information on the calcium and phosphorus balance of growing pigs, which received a ration recommended for dry lot feeding by the Iowa Agricultural Experiment Station. In addition, the data supplied information on the individual differences in the calcium and phosphorus retention of these pigs. The ration fed to all pigs during Period I was Ration A. The ingredients of this ration are presented in Table I, page 31. The pigs had been fed this ration for over one month preceding the test. The data collected in Period I are tabulated in Tables II and III. During the 14-day period each pig received five pounds of feed per day. This feed contained 16.04 grams of calcium and 12.17 grams of phosphorus. The amount of calcium retained per day ranged from 3.18 grams (pig No. 190) to 5.16 grams (pig No. 200), while the daily phosphorus retention ranged from 2.14 grams (pig No. 190) to 3.19 grams (pig No. 200). The calcium-phosphorus ratios for each pig were somewhat higher than the Ca:P ratio in the ration.

Period II. Low Level of Calcium Supplementation

Period II, which was undertaken following a two week transition period, was designed to compare the calcium and phosphorus retention of pigs No. 190, 200, and 210 when they were fed a low-calcium basal ration supplemented with ground limestone, steamed bone meal and Dicapho. The low-calcium ration used was Ration B, which is outlined in Table I. This ration contained 0.05 per cent

TABLE II

General Data (Trial I - Period I)

Pig No.	Age of pigs at beginning of period	Length of Period	Distinguishing features of ration	Daily Ration	Initial wt.	Final wt.	Ave. Daily Gain
	days	days		lbs.	lbs.	lbs.	lbs.
190	174	14	check	5	156.5	174.5	1.28
200	174	14	check	5	167.0	183.5	1.18
210	160	14	check	5	153.0	172.5	1.39

TABLE III

Daily Calcium and Phosphorus Balance (Trial I - Period I)

Pig No.	Calcium						Ration Ratio Ca:P
	Intake (gms.)	Outgo (gms.)			Retention (gms.)	Retention %	
		Feces	Urine	Total			
190	16.04	12.47	0.39	12.86	3.18	19.82	1.32:1
200	16.04	10.48	0.40	10.88	5.16	32.17	1.32:1
210	16.04	11.46	0.54	12.00	4.04	25.19	1.32:1
	Phosphorus						Retention Ratio Ca:P
190	12.17	8.58	1.45	10.03	2.14	17.58	1.49:1
200	12.17	7.63	1.35	8.98	3.19	26.21	1.62:1
210	12.17	7.64	1.56	9.20	2.97	24.40	1.36:1

calcium, and the calcium supplements were added in amounts to double the calcium intake. The experimental results are recorded in Tables IV and V.

On a daily feed intake of six pounds per day, the three pigs made average daily gains of approximately two pounds. The data in Table V show that all three pigs were in negative calcium balance, which was to be expected since they were receiving an intake of only slightly more than two grams per day. Pig No. 190, which received a limestone calcium supplement, had a negative balance of -0.09 grams of calcium per day, whereas the other two pigs receiving steamed bone meal and Dicapho had negative calcium balances of -0.30 grams per day. The daily phosphorus intake ranged from 6.69 grams for pig No.190 to 7.61 grams for pig No. 210. The phosphorus retention for each of the three pigs was approximately one gram per day. The ratio of calcium to phosphorus in the ration ranged from 0.33:1 in the limestone supplemented ration to 0.29:1 in the bone meal and Dicapho supplemented rations. The Ca:P retention ratios are not reported because the calcium balances of all pigs were negative.

Discussion:

It was intended to conduct a third period in Trial III in which the calcium supplements would have been added to the low-calcium basal ration in amounts to raise the calcium intake to that of Period I, but two of the experimental animals accidentally injured their dew-claws. The failure of the injured feet to heal necessitated a discontinuance of this trial.

TABLE IV

General Data (Trial I - Period II)

Pig No.	Age of pig at beginning of period	Length of Period	Distinguishing features of ration	Daily Ration	Initial wt.	Final wt.	Ave. Daily Gain
	days	days		lbs.	lbs.	lbs.	lbs.
190	206	10	Limestone	6	197.5	217	1.80
200	206	10	Bonemeal	6	212.0	232	1.80
210	192	10	Dicapho	6	201.0	223	2.00

TABLE V

Daily Calcium and Phosphorus Retention (Trial I - Period II)

Pig No.	Calcium						Ration Ratio Ca:P
	Intake (gms.)	Outgo (gms.) Feces	Urine	Total	Retention (gms.)	Retention %	
190	2.23	2.21	0.11	2.32	-0.09	-4.04	0.33:1
200	2.10	2.29	0.11	2.40	-0.30	-14.29	0.29:1
210	2.19	2.34	0.15	2.49	-0.30	-14.16	0.29:1
	Phosphorus						Retention Ratio Ca:P
190	6.69	4.94	0.62	5.56	1.13	16.89	(negative)
200	7.16	5.02	1.18	6.20	0.96	13.41	
210	7.61	5.22	1.21	6.43	1.18	15.50	

It may be seen in Table V that pig No. 190, fed the lime-stone supplemented ration, had a less negative calcium balance than the pigs which were fed the steamed bone meal and Dicapho. It is questionable however, if the difference is significant. Attention is drawn to the fact that the amount of phosphorus in the urine of pig No. 190 in Period II was 50 per cent less than the urinary phosphorus of the other pigs. This may be explained by the contention that phosphorus and other acid elements are necessary to maintain the optimum chemical reaction in the tissues when the base intake is increased by the ingestion of any base-rich material such as limestone.

2. Trial II

Period I. Check Ration

Calcium and phosphorus balance data were collected on four pigs in Period I. This was made possible due to the installation of a fourth metabolism crate. The pigs used in this period weighed approximately 60 pounds each. They were, therefore, much lighter in weight than the pigs used in Trial I.

The ration used in Period I was Ration C, the percentage composition of which is tabulated in Table I. This ration was very deficient in calcium, containing only 0.06 per cent. The purpose in undertaking Period I was twofold; first, to obtain information on the calcium and phosphorus retention of the pigs while all were receiving a similar ration, and second, to reduce their calcium reserve so that they would be more likely to respond, in Period II, to any difference which might exist in the availability of the calcium supplements. The data relating to

Period I are reported in Tables VI and VII.

According to the data in Table VII, the pigs received 0.57 gram of calcium and 2.41 grams of phosphorus per day; therefore, the calcium-phosphorus intake ratio was 0.24:1. The calcium balances were all negative and varied very little, while the phosphorus balances were positive, ranging from 0.13 grams to 0.25 grams per day. The data indicated little difference in the calcium and phosphorus metabolism of these pigs.

Period II. Low Level of Calcium Supplementation.

When Period I was terminated, the pigs were removed from the metabolism laboratory for 20 days. This procedure, while not desirable, was necessitated in order to make the metabolism crates available for metabolism Period I of Trial IV. During these 20 days the pigs were kept at the Animal Husbandry Experimental Farm in a dry lot, which was eight feet by 22 feet in size. It had a concrete floor and a covered pen six feet by eight feet in size. The pigs were fed from a self-feeder in the pen. The ration was similar to the ration they received in the metabolism laboratory in Period I, Trial II. During the period in which the pigs were absent from the laboratory, their growth rate dropped materially. In all probability this lower growth rate may be attributed to the continued use of the basal ration which was very deficient in calcium.

When the pigs were returned to the animal laboratory, the following allocation of rations was made: pig No. 610 was contin-

TABLE VI

General Data (Trial II - Period I)

Pig No.	Age of pig at beginning of period	Length of Period	Distinguishing features of ration	Daily Ration	Initial wt.	Final wt.	Ave. Daily Gain
	days	days		lbs.	lbs.	lbs.	lbs.
610	93	10	Check	2	54	65.5	1.15
634	93	10	Check	2	58	68.0	1.00
532	113	10	Check	2	55	64.5	0.95
630	93	10	Check	2	61	69.5	0.85

TABLE VII

Daily Calcium and Phosphorus Retention (Trial II - Period I)

Pig No.	Calcium						Ration Ratio Ca:P
	In-take (gms.)	Outgo (gms.)			Reten-tion (gms.)	Reten-tion %	
		Feces	Urine	Total			
610	0.57	0.83	0.16	0.99	-0.42	-73.68	0.24:1
634	0.57	0.86	0.15	1.01	-0.44	-77.19	0.24:1
532	0.57	0.80	0.12	0.92	-0.35	-61.40	0.24:1
630	0.57	0.90	0.11	1.01	-0.44	-77.19	0.24:1
	Phosphorus						Retention Ratio Ca:P
610	2.41	1.78	0.41	2.19	0.22	9.13	Negative
634	2.41	1.83	0.43	2.26	0.15	6.22	
532	2.41	1.72	0.44	2.16	0.25	10.37	
630	2.41	1.83	0.45	2.28	0.13	5.39	

ued on the basal ration (Ration C, Table I) and served as a negative control for pigs No. 532, 630, and 634, which received the basal ration supplemented with steamed bone meal, Dicapho, and ground limestone respectively. These compounds were added to the basal ration in amounts sufficient to increase the calcium intake of their rations to approximately that of Period II, Trial I.

In Tables VIII and IX the results of this period are presented. The daily calcium intake of pig No. 610 (check) was 0.59 grams as compared with 2.69 to 2.84 grams for the pigs which received the calcium supplements. The calcium-phosphorus ratio in the rations of the pigs which received the calcium supplements, ranged from 0.71:1 to 1.16:1. In each case the retention ratios of calcium to phosphorus were higher than the intake ratios. All pigs were in positive calcium balance with the exception of pig No. 610, which received the basal ration. Pig No. 634, which received limestone, had the highest calcium retention, 0.99 grams per day. The phosphorus retentions were all positive, ranging from 0.21 grams by pig No. 610 to 0.66 grams by pig No. 630.

Discussion:

A third period was initiated in which the calcium supplements were fed at high levels, but the pigs suffered an attack of influenza and as a result Trial II had to be terminated.

The data presented in Table VII demonstrate that all pigs retained approximately the same amount of calcium when all were

TABLE VIII

General Data (Trial II- Period II)

Pig No.	Age of pig at beginning of period	Length of Period	Distinguishing features of ration	Daily Ration	Initial wt.	Final wt.	Ave. Daily Gain
	days	days		lbs.	lbs.	lbs.	lbs.
610	134	10	Check	2	73.5	77.0	0.35
634	134	10	Limestone	2	79.0	83.5	0.45
532	154	10	Bonemeal	2	73.0	79.0	0.55
630	134	10	Dicapho	2	83.0	87.5	0.45

TABLE IX

Daily Calcium and Phosphorus Retention (Trial II - Period II)

Pig No.	Calcium						Ration Ratio Ca:P
	Intake (gms.)	Outgo (gms.) Feces	Urine	Total	Retention (gms.)	Retention %	
610	0.59	0.86	0.12	0.98	-0.39	-66.10	0.24:1
634	2.81	1.54	0.28	1.82	0.99	35.23	1.16:1
532	2.69	1.90	0.15	2.05	0.64	23,79	0.81:1
630	2.84	1.86	0.14	2.00	0.84	29.58	0.71:1
	Phosphorus						Retention Ratio Ca:P
610	2.43	2.00	0.22	2.22	0.21	8.64	-----
634	2.43	1.90	0.07	1.97	0.46	18.93	2.15:1
532	3.32	2.24	0.58	2.82	0.50	15.06	1.28:1
630	4.02	2.40	0.96	3.36	0.66	16.42	1.27:1

receiving a similar ration. In Table IX the data show that pig No. 634, which was fed the limestone supplemented ration, had a higher calcium retention than the pigs which received steamed bone meal and Dicapho supplemented rations. This is in accord with the results secured in Trial I but, as in Trial I, the differences were small. The calcium and phosphorus balance of the check pig No. 610 was practically the same in both periods, as may be seen in Tables VII and IX. The rate of gain for all pigs in Period II was much lower than in Period I. This lower daily gain in the second period was partly due to the continued use of the calcium-deficient ration fed during the 20 days between the two periods and partly due to the fact that, in Period II, the feed intake was not increased over that of Period I. The ration was not increased because all of the pigs would not maintain a good appetite on a higher level of feed intake, and it was essential that the feed intake of all pigs be the same.

3. Trial III: Period I. Check Ration

Four purebred Poland China barrows, weighing approximately 50 pounds each, were selected for Trial III. In Period I these pigs were fed Ration C, which is outlined in Table I. As in the first period of the preceding trial, the purpose in initiating Period I was twofold: first, to obtain data on the calcium and phosphorus balance of the pigs when all were receiving similar rations, and second, to lower their calcium reserves so that they would be more likely to reveal any differences which may exist in the relative efficiency of the calcium contained in ground limestone, steamed bone meal, and Dicapho.

The data collected in Period I are tabulated in Tables X and XI. The feed consumed by each pig in Period I was 1.5 pounds per day, and the average daily gain for each pig was approximately 0.5 pound. The ration had a calcium-phosphorus ratio of 0.29:1, and each pig received a daily intake of 0.70 grams of calcium and 2.38 grams of phosphorus. Because of the low calcium intake, all pigs had a negative calcium balance, which ranged from -0.03 grams (pig No.97) to -0.37 grams (pig No.111) per day. All phosphorus balances were positive. Pig No. 111, which had the greatest negative calcium balance, had the least positive phosphorus balance.

Period II. Low Level of Calcium Supplementation

As far as procedure is concerned, this period is a duplicate of Period II, Trial II. All four pigs were fed the same basal ration, namely, Ration C, the ingredients of which are tabulated in Table I. Pigs No. 111, 113, and 114 received ground limestone, steamed bone meal, and Dicapho respectively as calcium supplements to Ration C. Pig No. 97 was used as a negative control. These calcium supplements were added to the basal ration in amounts to raise the calcium intake of these pigs to that of the pigs fed the calcium supplemented rations in Period II of Trial II.

A summary of the data collected in Period II is given in Tables XII and XIII. On a daily ration of two pounds, each pig made a gain in weight of approximately 0.8 pound. The supple-

TABLE X

General Date (Trial III- Period I)

Pig No.	Age of pig at beginning of period	Length of Period	Distinguishing features of ration	Daily Ration	Initial wt.	Final wt.	Ave. Daily Gain
	days	days		lbs.	lbs.	lbs.	lbs.
97	82	10	check	1.5	51.25	56.50	0.52
111	81	10	check	1.5	53.00	57.50	0.45
113	81	10	check	1.5	51.75	57.25	0.55
114	81	10	check	1.5	52.50	57.00	0.45

TABLE XI

Daily Calcium and Phosphorus Retention (Trial III- Period I)

Pig No.	Calcium: In-take (gms.)	Outgo (gms.): Feces	Outgo (gms.): Urine	Outgo (gms.): Total	Reten-tion (gms.)	Reten-tion %	Ration Ratio Ca:P
97	0.70	0.64	0.09	0.73	-0.03	-4.28	0.29:1
111	0.70	0.95	0.12	1.07	-0.37	-52.86	0.29:1
113	0.70	0.90	0.05	0.95	-0.25	-35;71	0.29:1
114	0.70	0.79	0.08	0.87	-0.17	-24.28	0.29:1
	Phosphorus						Retention Ratio Ca:P
97	2.38	1.64	0.36	2.00	0.38	15.97	Negative
111	2.38	1.79	0.56	2.35	0.03	1.26	
113	2.38	1.70	0.45	2.15	0.23	9.66	
114	2.38	1.67	0.38	2.05	0.33	13.86	

TABLE XII

General Data (Trial III- Period II)

Pig No.	Age of pig at beginning of period	Length of Period	Distinguishing features of ration	Daily Ration	Initial wt.	Final wt.	Ave. Daily Gain
	days	days		lbs.	lbs.	lbs.	lbs.
97	98	10	Check	2	60.25	68.25	0.80
111	97	10	Limestone	2	60.50	68.50	0.80
113	97	10	Bonemeal	2	61.25	69.50	0.82
114	97	10	Dicapho	2	60.75	69.00	0.82

TABLE XIII

Daily Calcium and Phosphorus Retention (Trial III- Period II)

Pig No.	Calcium: Intake (gms.)	Outgo (gms.): Feces	Outgo (gms.): Urine	Outgo (gms.): Total	Retention (gms.)	Retention %	Ration -Ratio Ca:P
97	0.91	0.78	0.10	0.88	0.03	3.30	0.29:1
111	2.71	1.34	0.17	1.51	1.20	44.28	0.86:1
113	2.73	1.45	0.07	1.52	1.21	44.32	0.70:1
114	2.79	1.61	0.08	1.69	1.10	39.43	0.62:1
	Phosphorus						Retention Ratio Ca:P
97	3.16	2.14	0.36	2.50	0.66	20.89	-----
111	3.16	2.04	0.09	2.13	1.03	32.59	1.16:1
113	3.90	2.17	0.64	2.81	1.09	27.95	1.11:1
114	4.49	2.63	0.85	3.48	1.01	22.49	1.09:1

mented rations fed in Period II supplied a daily calcium intake of slightly more than 2.7 grams for each pig. The calcium-phosphorus ratios in the supplemented rations ranged from 0.62:1 (pig No. 114) to 0.86:1 (pig No.111). The retention Ca:P ratios were higher. The daily calcium balances of pigs No. 111, 113, and 114 differed only 0.1 gram, and the daily phosphorus balances of these pigs differed still less. In other words, the calcium and phosphorus retention of these pigs indicated practically no difference in the utilization of ground limestone, steamed bone meal, and Dicapho. Pig No. 97 which received the check ration, made daily gains similar to the other pigs, but his calcium and phosphorus retention was much lower than that of the others.

Period III. High Level of Calcium Supplementation

In all the preceding metabolism periods, with the exception of the initial periods in each trial, the rations were purposely designed to test the calcium supplements under the most rigid conditions, namely, subnormal levels of calcium intake. In contrast to this procedure, Period III was undertaken to ascertain the comparative utilization of the calcium supplements when added to a low-calcium basal ration in amounts sufficient to increase the daily calcium intake to a level comparable with that of recommended pig rations. As a matter of fact, the percentage of calcium in the ration actually fed was equivalent to the percentage of calcium in a ration composed of 80 per cent corn, 9.75 per cent tankage (7 per cent Ca.), 4.875 per cent linseed oilmeal, 4.875 per cent alfalfa meal, and 0.5 per cent salt (NaCl). The calcium intake of the three pigs receiving the calcium supplements was approximately three times greater in this period than in the previous one.

The results of this period are reported in Tables XIV and XV. The daily feed intake per pig during Period III was 2.5 pounds or 0.5 pound greater than in the preceding period. The daily intake of calcium for the pigs receiving the supplemented rations ranged from 8.09 to 8.68 grams. The daily phosphorus intake ranged from 3.95 grams for the pig which was fed the limestone supplemented ration, to 9.59 grams for the pig which was fed the ration supplemented with Dicapho. The calcium-phosphorus ratios of the supplemented rations ranged from 0.90:1 in the Dicapho ration, to 2.13:1 in the limestone supplemented ration. As in previous periods, the Ca:P retention ratios were somewhat higher than the intake ratios of these elements. Pig No. 111 retained 2.58 grams of calcium and 1.10 grams of phosphorus per day. These retentions were quite inferior to the calcium and phosphorus retention of pigs No. 113 and 114, as may be seen in Table XV. Pig No. 97 (check), which received basal ration C, continued to increase in weight during this period at a rate of over one pound per day, or, exactly the same amount that he gained in the preceding period.

It will be observed in Period III that pig No. 111, which received the limestone supplement, eliminated an abnormally high content of calcium in his urine. This elimination was over 10 times greater than the amount of calcium excreted in the urine of

TABLE XIV

General Data (Trial III - Period III)

Pig No.	Age of pig at beginning of period	Length of Period	Distinguishing features of ration	Daily Ration	Initial wt.	Final wt.	Ave. Daily Gain
	days	days		lbs.	lbs.	lbs.	lbs.
97	112	10	Check	2.5	73.25	83.75	1.05
111	111	10	Limestone	2.5	72.25	81.75	0.95
113	111	10	Bonemeal	2.5	73.00	83.50	1.05
114	111	10	Dicapho	2.5	73.00	83.00	1.00

TABLE XV

Daily Calcium and Phosphorus Retention (Trial III - Period III)

Pig No.	Calcium							
	Intake (gms.)	Outgo (gms.) Feces	Urine	Total	Retention (gms.)	Retention %	Ration Ratio Ca:P
97	1.14	1.01	0.10	1.11	0.03	2.63	0.29:1
111	8.40	4.40	1.42	5.82	2.58	30.71	2.13:1
113	8.09	3.89	0.11	4.00	4.09	50.56	1.12:1
114	8.68	4.59	0.13	4.72	3.96	45.62	0.90:1
	Phosphorus						Retention Ratio Ca:P
97	3.95	7.24	0.42	3.16	0.79	20.00	0.04:1
111	3.95	2.81	0.04	2.85	1.10	27.85	2.34:1
113	7.23	3.52	1.08	4.60	2.63	36.38	1.56:1
114	9.59	4.60	2.34	6.94	2.65	27.63	1.49:1

the other pigs in Period III. The wide Ca:P ratio in the ration of pig No. 111 may have been a factor in causing this shift in calcium excretion from the feces to the urine. Determinations of the urinary pH of pig No. 111 indicated a disturbed acid-base balance, which also may have been a factor in causing the shift.

The use of litmus paper as an indicator demonstrated that there was a large difference in the acidity of the urine excreted by the four pigs. In order to express this difference quantitatively, pH determinations were made on the urine. The readings were taken by the use of the quinhydrone electrode and saturated calomel half cell. The average pH of the urine excreted by each pig is given in Table XVI. These values are the averages of ten readings made on the urine of each pig at approximately equal intervals during a 48-hour period. It was found that individual readings on the same pig did not vary beyond 0.3 in pH.

In view of the possibility that pH determinations on the feces of the pigs might shed some light on the large differences in urinary pH, four determinations were made on the feces excreted during the latter half of the above mentioned 48-hour period. The average of four readings is given in Table XVI.

TABLE XVI

pH Numbers of Urine and Feces (Trial III - Periods III and IV)

Pig No.	Distinguishing features of ration	pH of Urine		pH of Feces
		Period III	Period IV	Period III
97	Check	6.5	6.6	6.10
111	Limestone	7.8	6.8	6.70
113	Bonemeal	5.9	6.2	6.40
114	Dicapho	5.6	5.7	6.30

It is interesting to note the effect of the various rations on the pH of the urine. The addition of limestone to a potentially acidic ration raised the urinary pH, whereas the addition of steamed bone meal and Dicapho to a potentially acidic ration lowered the pH of the urine. These results are supported by data reported by other investigators (29), (72). The average pH values for the feces of the pigs did not differ enough to warrant any conclusion.

In this period where limestone was used as a supplement in a large amount, the urine was alkaline in reaction. There was a less favorable retention of calcium and phosphorus, and there was a remarkably large excretion of calcium in the urine.

Period IV. High Level of Calcium Supplementation

Period IV was undertaken to study the effect of adding a neutral mixture of mono- and di-sodium phosphate to a limestone supplemented ration similar to the one used in Period III. Moreover, Period IV served in part as a check on the data collected in Period III. The basal ration used in Period IV was Ration C, the percentage composition of which is presented in Table I. The calcium supplements were added to Ration C in amounts similar to those added in the preceding period. In order to raise the phosphorus content of the limestone supplemented ration to that of the bone meal supplemented ration fed in Trial III, Period III, a neutral mixture of mono- and di-sodium phosphate was added. This phosphate mixture was added to the extent of 1.3 per cent of the basal ration.

The pigs used during the three preceding periods were again the experimental animals in this period. In the intervening time between Period III and Period IV, pig No. 114 was sick for two days, and his condition could not be diagnosed. For a few days his rate of gain diminished, and as a result, he was lighter than the other pigs at the beginning of Period IV.

After a preliminary feeding period of seven days Period IV began. The data collected in this period are tabulated in Table XVII and XVIII. During the period the average daily ration of each pig was 2.5 pounds. The daily gains made by the pigs which received the calcium supplements ranged from 0.75 pound to 0.90 pound. As can be seen in Table XVIII, the daily calcium intake of each pig which received a supplemented ration was over eight grams. The daily phosphorus intake ranged from 7.27 grams (pig No. 111) to 9.65 grams (pig No. 114). The calcium-phosphorus ratio of the limestone-sodium phosphate supplemented ration was

TABLE XVII

General Data (Trial III - Period IV)

Pig No.	Age of pig at beginning of period	Length of Period	Distinguishing features of ration	Daily Ration	Initial wt.	Final wt.	Ave. Daily Gain
	days	days		lbs.	lbs.	lbs.	lbs.
97	141	10	Check	2.5	99.00	102.00	0.30
111	140	10	Limestone & Sodium Phosphate	2.5	98.00	105.50	0.75
113	140	10	Bonemeal	2.5	97.75	106.75	0.90
114	140	10	Dicapho	2.5	89.00	96.50	0.75

TABLE XVIII

Daily Calcium and Phosphorus Retention (Trial III-Period IV)

Pig No.	Intake (gms.)	Outgo (gms.) Feces	Urine	Total	Retention (gms.)	Retention %	Ration Ratio Ca:P
		Calcium					
97	1.14	1.13	0.10	1.23	-0.09	-7.89	0.29:1
111	8.09	5.35	0.08	5.43	2.66	32.88	1.11:1
113	8.15	4.97	0.12	5.09	3.06	37.55	1.11:1
114	8.69	6.09	0.13	6.22	2.47	28.42	0.90:1
		Phosphorus					Retention Ratio Ca:P
97	3.95	3.04	0.51	3.55	0.40	10.13	———
111	7.27	4.79	1.22	6.01	1.26	17.33	2.11:1
113	7.33	3.78	1.05	4.83	2.50	34.11	1.22:1
114	9.65	5.32	1.94	7.26	2.39	24.77	1.03:1

1.11:1 as compared to a Ca:P ratio of 2.13 for the limestone ration of the previous period. Of those which received the calcium supplements, pig No. 113 had the highest daily calcium retention (3.06 grams), and pig No. 114 had the lowest daily calcium retention (2.47 grams). It is evident, therefore, that the differences in the calcium retention of the pigs which received the supplemented rations are much smaller than in the preceding period. The phosphorus retention of pig No. 111 did not improve greatly over Period III, and the retention was still inferior to that of pigs No. 113 and No. 114.

The negative control pig No. 97, which received the low-calcium basal ration, showed in this period the detrimental effects which follow the long continued use of a calcium-deficient ration in the absence of ultra-violet light or any concentrated form of vitamin D. In the three previous periods pig No. 97 continued to increase in weight at a rate equal to any of the pigs receiving the calcium supplemented rations. In this period his rate of daily gain in weight had fallen to one-third of that in the previous period. His joints became enlarged and his legs were crooked and stiff, both of which are clinical symptoms of rickets. It was remarkable the resistance this pig displayed against rickets, since, on the average, he had received less than one gram of calcium per day for a period of nine weeks before showing visible signs of physical disturbance.

The most significant result obtained in Period IV was the drop in the urinary calcium of pig No. 111, from an abnormally high value of 1.42 grams per day (Period III) to a more normal value of 0.08 grams per day in this period. Moreover, the pH of the urine of pig No. 111 changed from an alkaline to an acid reaction (Table XVI).

Table XVI (page 56) gives the average pH number of the urine. The values are the average of four readings taken at approximately equal intervals during a 24-hour period. The values for pigs No. 97, 113, and 114 are slightly higher than those taken in the previous period, while the pH of the urine of pig No. 111 is much lower. The addition of sodium phosphate to the limestone ration of pig No. 111 was no doubt an important factor in causing his urinary pH to return to a more normal value.

Bone Analyses on Pigs Used in Trial III

All four pigs used in Trial III were slaughtered following the termination of period IV. The femurs and humeri were removed for chemical analysis. The green bones were freed of all adhering flesh, weighed to the nearest tenth of a gram, and measured in length. They were then subjected to breaking strength tests by the use of a Tinius Olson Universal Machine. The values, for breaking strength were expressed in pounds pressure. The values, however, were rather low due to the manner in which the bones were broken. The distal and proximal ends were laid across the narrow ends of two anvil supports having a span of 8.5 centimetres. Pressure was applied to the diaphysis at the centre of the span. The conditions maintained in this set-up produced lower breaking strength values as compared to those employed by other investigators (29), (58). This method, however, was satisfactory in determining the relative strength of the bones. After breaking strength tests had been made, each bone was crushed, then carefully wrapped in filter paper and extracted for ten days — three days with alcohol and ether, and seven days with hot alcohol by means of an improvised Soxhlet extractor — to remove all ether-alcohol soluble substances. The bones were dried to constant weight in an electric oven at 100° C., and the fat-free weight recorded to the nearest milligram. Each entire bone was burned to a char over an open flame, then the ashing was completed by the use of a muffled furnace. The ash of each bone was weighed to the nearest milligram. The total bone ash obtained from each bone was dissolved in dilute hydrochloric acid, dehydrated to precipitate any silica present, filtered, made up to volume, and aliquoted for analysis of calcium and phosphorus by the methods mentioned on page 37.

A study of these data, as presented in Table XIX, shows that pig No. 97, which received the check ration, had bones quite inferior in strength and quantity of ash to the other three pigs receiving the calcium supplemented rations. Breaking strength and per cent ash values were highest for pig No. 113, which received the bone meal supplemented ration, and least for pig No. 111, which received the limestone supplemented ration. The val-

TABLE XIX

SUMMARY OF BONE ANALYSI

Pig No.	Bone	Length (over all) c.m.	Breaking Strength 8.5 c.m. span lbs.	Green Weight gms.	Fat-Free Dry Weight gms.	Bone-Ash Weight gms.	Ash of Dry Weight %	Total Calcium in Bone gms.
	*R.F.	16.4	285	164	55.39	24.39	44.03	9.43
97	L.F.	16.3	270	158	54.47	23.50	43.15	9.08
	R.H.	14.1	275	151	53.02	23.58	44.49	9.08
	L.H.	14.1	260	148	52.73	23.26	44.11	8.97
	R.F.	17.6	300	187	59.45	30.58	51.44	12.00
111	L.F.	17.6	320	190	59.74	31.02	51.94	12.22
	R.H.	15.0	345	177	58.91	30.97	52.57	12.18
	L.H.	15.1	325	177	59.19	30.91	52.22	12.15
	R.F.	18.3	480	187	66.70	36.34	54.48	14.15
113	L.F.	18.4	540	187	67.50	36.69	54.36	14.29
	R.H.	15.3	515	172	63.93	35.48	55.50	13.83
	L.H.	15.3	430	174	64.39	35.23	54.72	13.65
	R.F.	17.1	330	169	55.34	29.73	53.72	11.47
114	L.F.	17.2	290	172	56.52	29.94	52.97	11.58
	R.H.	14.4	445	158	55.02	29.91	54.37	11.65
	L.H.	14.5	410	159	55.02	30.05	54.62	11.68

* R.F. Right femur
L.F. Left femur
R.H. Right humerus
L.H. Left humerus

TABLE XIX

RY OF BONE ANALYSES

Ash of Dry Weight %	Total Calcium in Bone gms.	Calcium in Fat-Free Bone %	Calcium in Ash %	Total Phosphorus in Bone gms.	Phosphorus in Fat-Free Bone %	Phosphorus in Bone Ash %
44.03	9.43	17.02	38.66	4.48	8.09	18.37
43.15	9.08	16.67	38.64	4.29	7.88	18.28
44.49	9.08	17.12	38.51	4.29	8.09	18.19
44.11	8.97	17.01	38.56	4.23	8.02	18.18
51.44	12.00	20.18	39.24	5.77	9.70	18.87
51.94	12.22	20.46	39.39	5.86	9.81	18.89
52.57	12.18	20.68	39.33	5.85	9.93	18.89
52.22	12.15	20.53	39.31	5.86	9.90	18.96
54.48	14.15	21.21	38.94	6.78	10.16	18.66
54.36	14.29	21.17	38.95	6.84	10.13	18.64
55.50	13.83	21.63	38.98	6.67	10.43	18.80
54.72	13.65	21.20	38.75	6.55	10.17	18.59
53.72	11.47	20.73	38.58	5.45	9.85	18.33
52.97	11.58	20.49	38.68	5.46	9.66	18.24
54.37	11.65	21.17	38.95	5.54	10.07	18.52
54.62	11.68	21.23	38.87	5.57	10.12	18.54

ues for pig No. 114, fed the Dicapho supplement, were intermediate; the differences, however, were small. The percentage of ash was slightly higher in the humeri of all pigs than in the femurs. The percentage of calcium and phosphorus in the bone ash of all pigs was similar, averaging around 18.5 per cent phosphorus and 39.0 per cent calcium. When the percentages of calcium and phosphorus were based on the dry bone, they were much less for the check pig (No. 97) than for the others. The check pig had 17 per cent calcium and eight per cent phosphorus, while the other pigs had approximately 20 per cent calcium and 10 per cent phosphorus.

Discussion:

Data, collected in Period II of this trial, demonstrate that when limestone, bone meal, and Dicapho were fed at low intake levels as supplements to a low-calcium ration, the pigs utilized them with almost equal efficiency. This result is in agreement with the results obtained in Trials I and II. The differences in calcium and phosphorus retention of pigs No. 111, 113, and 114, were greater in Period I, when all pigs were fed the check ration, than in Period II. This would indicate that the individuality of the pigs might account for the differences in Period II.

In Period III the calcium supplements were added to the basal ration at high levels. In this period the pigs which were fed bone meal (No. 113) and Dicapho (No. 114), retained much more calcium and phosphorus than pig No. 111, which received a limestone supplemented ration. The calcium excretion in the urine of pig No. 111 during Period III was abnormally high, and it had an alkaline reaction. In Period IV, when a neutral mixture of sodium phosphate was included in the ration of pig No. 111, the retention of calcium was similar to that of pigs No. 113 and 114 during Period IV. The pH and calcium content of the urine of pig No. 111 had returned to normal in Period IV. These data indicate that the change in the calcium-phosphorus intake ratio, from 2.13:1 in the limestone supplemented ration to 1.11:1 in the limestone neutral phosphate supplemented ration, were factors in improving the retention of pig No. 111.

Determination of the breaking strength, ash, calcium, and phosphorus of the bones of pigs No. 111, 113, and 114 indicate little difference in their composition.

Pig No. 97, which served as a negative control during Trial III, showed no external symptoms of calcium deficiency for a period of nine weeks. During this time his calcium intake averaged less than one gram per day, and vitamin D was absent from his diet in any concentrated form. During the tenth week he developed symptoms of rickets and disturbed metabolism.

4. Trial IV.

Period I. High Level of Calcium Supplementation

Trial IV was undertaken to determine the calcium and phosphorus retention of representative barrows from Lots II, IV, VI, and VIII in Series II of the Feed Lot Experiment reported in Part II of this thesis. The first period was conducted during the early part of the Feed Lot Experiment when the barrows weighed between 106 and 114 pounds each.

The following representative barrows were selected: Lot II, pig No. 3046; Lot IV, pig No. 3018; Lot VI, pig No. 3014; Lot VIII, pig No. 197. Each of these barrows was fed a similar ration (during the metabolism trial) to that which he received in the feed lot. The percentage composition of the rations fed to these pigs, is given in Table XXVI (first 30-day period), page 78. The amount of the calcium supplements added to the check ration (on an equivalent calcium basis) was based upon data collected in previous experiments, wherein 140 pigs of approximately the same age and weight as those used in this experiment, were fed a basal ration similar to the one used in this experiment. These 140 pigs were fed a mineral mixture free-choice style. The amount of supplemental calcium in the mineral mixture consumed, was as follows: first 30 days, 4.2 grams; second 30 days, 3.35 grams; third 30 days, 2.04 grams. These figures served as a practical basis for the calculation of the amount of the three calcium compounds used as supplements.

The data relating to Period I are summarized in Tables XX and XXI. The feed consumed by each pig in Period I amounted to four pounds per day. The average daily gain for each pig was approximately 1.3 pounds. The supplemented rations fed supplied a daily calcium intake of 17.3 grams each, while the check ration supplied 13.86 grams of calcium. The phosphorus intake of the four pigs ranged from 11.09 grams for pig No. 3046 to 13.37 grams for pig No. 197. The calcium and phosphorus retentions for all pigs were quite similar. As in previous trials, the urinary phosphorus of the pig receiving the limestone was much lower than that of the other three pigs.

Period II. Low Levels of Calcium Supplementation

At the termination of Period I the pigs were returned to the dry lots from which they had been taken. After five weeks time they were again transferred to the metabolism crates in the animal laboratory for another test. The rations fed during this period were the same as those fed during the last period of the Feed Lot Experiment. The percentage composition of the rations are reported in Table XXVI (10-17.5 day period), page 78.

The daily calcium intake of all pigs in Period II was considerably less than that of the preceding period. This is partly accounted for by the reduction of trinity mixture in the ration, and partly due to the lower level of calcium supplementation. It was necessary to decrease the amount of trinity mixture in the ration and increase the corn in order that the nutritive ratio would conform to a recommended standard (39) for pigs weigh-

TABLE XX.

General Data (Trial IV - Period I)

Pig No.	Age of pig at beginning of period	Length of Period	Distinguishing features of ration	Daily Ration	Initial wt.	Final wt.	Ave. Daily Gain
	days	days		lbs.	lbs.	lbs.	lbs.
3046	133	14	Check	4	109.50	128.00	1.32
3018	146	14	Limestone	4	112.00	130.50	1.32
3014	146	14	Bonemeal	4	106.50	124.50	1.29
197	156	14	Dicapho	4	113.50	132.00	1.32

TABLE XXI.

Daily Calcium and Phosphorus Retention (Trial IV- Period I)

Pig No.	Calcium						Ration Ratio Ca:P
	In-take (gms.)	Outgo (gms.) Feces	Urine	Total	Retention (gms.)	Retention %	
3046	13.86	9.23	0.26	9.49	4.37	31.53	1.25:1
3018	17.39	12.38	0.20	12.58	4.81	27.66	1.57:1
3014	17.32	12.42	0.24	12.66	4.66	26.90	1.43:1
197	17.36	12.62	0.22	12.84	4.52	26.04	1.30:1
	Phosphorus						Retention Ratio Ca:P
3046	11.09	6.86	1.45	8.31	2.78	25.07	1.57:1
3018	11.05	7.37	0.67	8.04	3.01	27.24	1.60:1
3014	12.12	8.19	1.65	9.84	2.28	18.81	2.04:1
197	13.37	8.74	1.86	10.60	2.77	20.72	1.63:1

ing 200 pounds. Since trinity mixture contains 50 per cent tankage, and inasmuch as the tankage used contained seven per cent calcium, a reduction in this ingredient materially reduced the calcium content of the ration. It will be recalled from Period I that the amount of calcium added to the check ration was calculated from data obtained in previous experiments. In these previous experiments the amount of supplemental calcium consumed by the pigs weighing 200 pounds was considerably less than that consumed by the younger pigs.

Data pertaining to Period II are tabulated in Tables XXII and XXIII. In this period each pig received six pounds of feed per day. The daily calcium intake of the pigs fed the supplemented rations was slightly more than 12 grams each. The daily phosphorus intake of these pigs ranged from 12.14 to 12.97 grams, and as a result the Ca:P ratio in the ration was quite narrow, 0.93 — 0.99:1.

The retention data in Table XXIII show that pig No. 3018 had a slightly higher retention of calcium and phosphorus than that of the other pigs. The retention ratios of calcium to phosphorus were higher than the intake ratios in every case.

Period III. Check Ration

In preceding trials the check period preceded the periods during which the supplements were tested. In this trial the order was reversed, in that two periods wherein calcium supplements were fed, were followed by a check period. Pigs No. 197,

TABLE XXII

General Data (Trial IV- Period II)

Pig No.	Age of pig at beginning of period	Length of Period	Distinguishing features of ration	Daily Ration	Initial wt.	*Final wt.	Ave. Daily Gain
	days	days		lbs.	lbs.	lbs.	lbs.
3046	174	14	Check	6	175.0	194.70	1.41
3018	187	14	Limestone	6	180.0	201.80	1.56
3014	187	14	Bonemeal	6	175.0	193.50	1.32
197	197	14	Dicapho	6	172.0	192.20	1.44

TABLE XXIII

Daily Calcium and Phosphorus Retention (Trial IV- Period II)

Pig No.	Intake (gms.)	Outgo (gms.) Feces	Urine	Total	Retention (gms.)	Retention %	Ration Ratio Ca:P
	Calcium						
3046	10.87	7.49	0.31	7.80	3.07	28.24	0.90:1
3018	12.02	8.27	0.22	8.49	3.53	29.37	0.99:1
3014	12.14	8.66	0.44	9.10	3.04	25.04	0.96:1
197	12.02	8.75	0.34	9.09	2.93	24.38	0.93:1
	Phosphorus						Retention Ratio Ca:P
3046	12.14	7.39	2.23	9.62	2.52	20.76	1.22:1
3018	12.14	7.46	1.36	8.82	3.32	27.35	1.06:1
3014	12.59	8.38	1.40	9.78	2.81	22.32	1.08:1
197	12.97	7.88	2.23	10.11	2.86	22.05	1.02:1

* An estimated weight as no weight was taken between periods II and III.

3011, and 3014, which received the supplemented rations in Periods I and II, were changed to a check ration similar to the one fed to pig No. 3046 in Period II. The ingredients of this ration (Ration E) are tabulated in Table I.

The purpose of conducting this period was to obtain information on the calcium and phosphorus retention of the four pigs when all received a similar ration. It was thought that this information would be of value in interpreting the results obtained in Periods I and II.

The data collected during this period are reported in Tables XXIV and XXV. The ration fed in Period III had a calcium-phosphorus ratio of 0.9:1. Six pounds of this ration were fed to each pig daily, and this amount supplied a daily intake of 10.89 grams of calcium and 12.06 grams of phosphorus. Pig No. 3018 had the highest calcium and phosphorus retention amounting to 3.14 grams of calcium and 2.98 grams of phosphorus per day. The retention values for the other pigs were quite similar to each other.

Discussion:

It is evident from the data presented in Trial IV that there was no advantage in supplementing the basal ration with calcium, since the average daily gains and calcium and phosphorus retention values were quite similar for all four pigs in each period. In Period I, pig No. 3018, which was fed the limestone supplemented ration, had a slightly higher calcium balance than the other pigs. In Period II, this was again borne out. In Period

TABLE XXIV

General Data (Trial IV - Period III)

Pig. No.	Age of pig at beginning of period	Length of Period	Distinguishing features of ration	Daily Ration	Initial wt.	Final wt.	Ave. Daily Gain
	days	days		lbs.	lbs.	lbs.	lbs.
3046	193	7	Check	6	*213.10	223.00	1.41
3018	206	7	Check	6	222.10	233.00	1.56
3014	206	7	Check	6	210.80	220.00	1.32
197	216	7	Check	8	206.90	217.00	1.44

TABLE XXV

Daily Calcium and Phosphorus Retention (Trial IV - Period III)

Pig No.	Calcium							Ration Ratio Ca:P
	Intake (gms.)	Outgo (gms.) Feces	Urine	Total	Retention (gms.)	Retention %		
3046	10.89	7.69	0.28	7.97	2.92	26.81		0.90:1
3018	10.89	7.45	0.30	7.75	3.14	28.83		0.90:1
3014	10.89	8.03	0.46	8.49	2.40	22.04		0.90:1
197	10.89	8.10	0.28	8.38	2.51	23.05		0.90:1
	Phosphorus							Retention Ratio Ca:P
3046	12.06	7.34	2.06	9.41	2.65	21.97		1.10:1
3018	12.06	7.46	1.62	9.08	2.98	24.71		1.05:1
3014	12.06	7.99	1.32	9.31	2.75	22.80		0.87:1
197	12.06	7.44	1.87	9.31	2.75	22.80		0.91:1

* An estimated weight as no weights were taken between periods II and III.

III, however, where all pigs received a similar ration, pig No. 3018 continued to retain a greater amount of calcium than the other pigs. It would seem then that the somewhat higher calcium retention of pig No. 3018 was not due to the limestone supplemented ration, but rather to the individuality of this pig.

D. Discussion of Experimental Results

When ground limestone, steamed bone meal, and Dicapho were fed at low levels as calcium supplements to a calcium-deficient ration, the calcium-phosphorus retention data indicated practically no difference in their utilization. When these same supplements were fed at high levels, the calcium and phosphorus retention of the pig receiving the limestone supplemented ration was lower than the retention of the other pigs. The lower retention of the pig fed the limestone ration may have been due to one or both of the following factors:

(1) The calcium-phosphorus ratio and vitamin D.

The Ca:P ratio in this ration was 2.13:1, and inasmuch as the ration was practically devoid of vitamin D, this ratio may have been too wide for satisfactory results. This contention is supported by a number of experiments (12), (59), (86).

(2) The acid-base balance.

The pig receiving the limestone excreted an alkaline reacting urine which contained an abnormally high content of calcium. Other investigators have found that the acid-base balance is a factor to be reckoned with in calcium and phosphorus metabolism (32), (84).

The less favorable results secured when limestone was fed at high levels as a supplement were overcome by the addition of a neutral mixture of mono- and di-sodium phosphate to the ration. A sufficient amount of the phosphate mixture was added to change the Ca:P ratio in the ration from 2.13:1 to 1.11:1. It is evident therefore, that so long as the calcium-phosphorus relationship in the ration is satisfactory, limestone is just as valuable as a calcium supplement as steamed bone meal and Dicapho.

The Ca:P retention values of four representative pigs, taken from the feed lot experiment and reported in Part II of this thesis, demonstrate no difference in the utilization of limestone, bone meal and Dicapho. The data indicate moreover, no advantage in adding supplemental calcium and phosphorus to a ration composed of corn, tankage, linseed oilmeal, alfalfa meal, and salt.

Part II: Feed Lot Experiment

A. Object of the Experiment

This experiment was conducted to determine: (1) The efficacy of ground limestone, steamed bone meal, and Dicapho as calcium supplements to a practical ration which is fed widely in dry lot to growing and fattening pigs. (2) The advisability of adding calcium to a practical hog growing ration composed of corn and trinity mixture (tankage, linseed oilmeal, and alfalfa meal).

B. Outline of Experiment

On August 10, 1932 eighty Poland China feeder pigs, purebred and crossbred, averaging 88 pounds in weight, with an average age of 112 days, were divided into eight lots of 10 pigs each. Weight, breed, sex, age, condition and probable outcome were factors considered in making the allotments. Lots I, III, V, and VII formed Series I, while lots II, IV, VI, and VIII formed Series II. Each series served as a replicate of the other in treatment except that, on two different occasions, a representative barrow from each lot in Series II was removed for metabolism trials. The first removal was made on August 29th, and the barrows were returned 21 days later. These same pigs were again transferred to the metabolism crates on October 10th and returned to their lots 32 days later.

The purpose of taking one pig from each lot in Series II was to determine the calcium and phosphorus retention of each barrow while he was receiving a weighed amount of the same rations each pig had been receiving when in the feed lot. The following representative pigs were selected from the lots: Lot II, pig No. 3046; Lot IV, pig No. 3018; Lot VI, pig No. 3014; Lot VIII, pig No. 197. Data on the calcium and phosphorus retention of these pigs are presented in Part I (Trial IV) of this thesis.

The experiment terminated when each lot of pigs reached an average liveweight of 225 pounds. A tabulated outline of the experiment follows:

Series No.	Lot No.	No. of Pigs	Distinguishing Features of Ration	Statistics Collected
I	I	10	Basal ration	1. Gain in liveweight
	III	10	Basal ration + ground limestone	
	V	10	Basal ration + steamed bonemeal	2. Feed consumption per 100 lbs. gain in liveweight
	VII	10	Basal ration + Dicapho	
II	II	10	Basal ration	1. Gain in liveweight
	IV	10	Basal ration + ground limestone	2. Feed consumption per 100 lbs. gain in liveweight
	VII	10	Basal ration + steamed bonemeal	
	VIII	10	Basal ration + Dicapho	3. Calcium and phosphorus balance data

C. Animals Used

The 80 pigs used in this experiment were all raised on the Animal Husbandry Experimental Farm and were purebred Poland China or crossbred (Poland China-Duroc Jersey cross and Poland China-Yorkshire cross).

The dams of the pigs received similar treatment previous to and after farrowing. Most of the pigs were farrowed during April;

this made them slightly more than three and one-half months old when the experiment began. The male pigs were castrated, and all the pigs were treated for hog cholera before weaning. From weaning until the experiment began, all pigs received a good growing ration and had access to pasture.

D. Housing and Equipment

Each group of pigs had access to a dry lot 26 feet by 120 feet. In each lot there was a movable house which had a gable roof, a plank floor, and was 10 feet by 12 feet in size. Each house was equipped with two self-feeders. The troughs of these feeders were divided into three compartments, each compartment having a separate cover. These covers practically eliminated waste of feed, for they fell into place when the pigs withdrew their heads after feeding. Water was supplied by large galvanized water tanks placed in the dry lots.

E. Rations and Method of Feeding

The basal (check) ration used in this experiment was composed of ground corn and trinity mixture (meat meal tankage 50 per cent, linseed oilmeal 25 per cent, and alfalfa meal 25 per cent).

The amount of calcium added to the basal ration was determined by the utilization of data from previous hog feeding experiments. In the previous experiments, 140 pigs of approximately the same age and weight as those used in this experiment, were fed free-choice style a ration similar to the one fed in this experiment. The average daily amount of supplemental calcium (Ca.) consumed by these 140 pigs was as follows: First 30 days, 4.2 grams; second 30 days, 3.35 grams; third 30 days, 2.04 grams.

These figures served as a practical basis for the calculation of the amounts of the three calcium compounds used in this feed lot experiment. At the beginning of each 30-day period the amounts of supplemental calcium were changed in accordance with the above figures.

The ingredients of the rations were finely ground and then mixed by means of a MacLellan Rotary Batch Mixer. The ration was prepared and mixed at the beginning of each 30-day period. It was fed in dry form and free-choice style. In other words, the pigs had access to feed in the self-feeders at all times. Water was always available to the pigs in large galvanized water tanks. The percentage composition of the rations fed in the experiment is given in Table XXVI.

F. Collection of Data

Data were collected on the average daily gains in weight made by the pigs, the average feed consumed by the pigs in each lot, and the average feed required per pig per 100 pounds gain in liveweight. Each pig was weighed on three consecutive days at the beginning and end of the experiment. The averages of these three initial and three final weights were taken as the initial and final weights respectively. In addition, individual weights were taken every 30 days during the experiment.

Weighed amounts of feed were placed in the self-feeders and weigh-backs of uneaten feed were made every ten days. These data for 10-day periods were grouped at the end of each 30-day period

TABLE XXVI

Percentage Composition of Rations

* Series I Lot	Series II Lot	Ingredients	Percentage Composition 1st 30 days	2nd 30 days	Remainder of exp. period (10-17.5 days)
I	II	Ground corn	80.000	80.000	90.000
		Tankage	9.750	9.750	4.750
		Linseed oilmeal	4.875	4.875	2.375
		Alfalfa meal	4.875	4.875	2.375
		Salt	0.500	0.500	0.500
			100.000	100.000	100.000
III	IV	Ground corn	79.410	79.680	89.856
		Tankage	9.750	9.750	4.750
		Linseed oilmeal	4.875	4.875	2.375
		Alfalfa meal	4.875	4.875	2.375
		Salt	0.500	0.500	0.500
		Ground limestone	0.590	0.320	0.144
			100.000	100.000	100.000
V	VI	Ground corn	79.300	79.630	89.830
		Tankage	9.750	9.750	4.750
		Linseed oilmeal	4.875	4.875	2.375
		Alfalfa meal	4.875	4.875	2.375
		Salt	0.500	0.500	0.500
		Steamed bonemeal	0.700	0.370	0.170
			100.000	100.000	100.000
VII	VIII	Ground corn	79.190	79.570	89.803
		Tankage	9.750	9.750	4.750
		Linseed oilmeal	4.875	4.875	2.375
		Alfalfa meal	4.875	4.875	2.375
		Salt	0.500	0.500	0.500
		Dicapho	0.810	0.430	0.197
			100.000	100.000	100.000

* Note that Series II is a replication of Series I.

so that a 30-day summary was available as well as a total experiment summary for each lot.

It will be recalled that, on two different occasions, one pig was removed from each lot in Series II for the purpose of determining his calcium and phosphorus retention. The amount of feed consumed by each of these pigs, while in the metabolism laboratory, was added to the amount consumed by the remaining nine pigs of his lot. The gain in weight made by each of these pigs while in the metabolism laboratory, was credited to the data on gains in weight for the lot from which he was taken.

G. Health of Animals

The animals were in healthy condition when the experiment began and remained so until the experiment had been in progress about 50 days. At this time all lots were affected by a light attack of influenza. Lot I, according to general observation, was most affected, while Lots II, IV, V, and VII were least affected; however, as may be seen from the experimental data, none of the pigs could have been seriously ill. It is believed that the sudden change to cold fall weather was the cause of the influenza outbreak. In less than a week following the outbreak the pigs had improved greatly, and during the remainder of the experiment, they continued in excellent health, with the exception of one pig in Lot VI whose death on October 3rd was attributed to pneumonia.

H. Experimental Results

In order to gain a perspective of the experimental results a summary of the data collected is tabulated in Table XXVII. The average feed consumption and daily gains in liveweight are given detailed presentation under separate headings in Tables XXVIII and XXIX.

TABLE XXVII

Summary of Data

Series No.	Lot No.	No. pigs in lot	Distinguishing features of ration	Ave. Initial wt.	Length of time required to attain approx. 225 lbs. liveweight	Ave. Daily gain in wt. per pig	Feed required for 100 lbs. gain in liveweight
				lbs.	days	lbs.	lbs.
I	I	10	Check	89.00	74.0	1.84	396.31
	III	10	Limestone	88.23	77.5	1.76	391.26
	V	10	Bonemeal	88.10	77.5	1.76	389.22
	VII	10	Dicapho	88.40	76.0	1.80	381.15
II	II	10	Check	89.07	77.5	1.76	386.95
	IV	10	Limestone	87.97	73.5	1.86	371.39
	VI	10	Bonemeal	87.60	75.5	1.81	385.88
	VIII	10	Dicapho	88.57	74.0	1.84	379.29

1. Daily Gain in Liveweight

TABLE XXVIII

Average Daily Gains in Liveweight (lbs.)

Distinguishing Features of Ration	Check		Limestone		Bonemeal		Dicapho	
	Lot I	Lot II	Lot III	Lot IV	Lot V	Lot VI	Lot VII	Lot VIII
Series No. I	1.84		1.76		1.76		1.80	
Series No. II		1.76		1.86		1.81		1.84
Average	1.80		1.81		1.78		1.82	

The date in Table XXVIII show that the pigs made high average daily gains and that the difference in gains between the lots was small. In Series I, the daily increase in liveweight ranged from 1.76 pounds per day in Lots III and V to 1.84 pounds in Lot I. In Series II, the gains ranged from 1.76 pounds in Lot II to 1.86 pounds per day in Lot IV. This difference, which amounts to 0.1 pound, is the largest difference in average daily gains between any two lots within either series or between the series themselves. In reference to the statistical significance of a difference of 0.1 pound, it has been the experience of the Iowa Agricultural Experiment Station that differences up to 0.14 pound may be expected from individual variations in pigs under controlled conditions. One can conclude with considerable assurance, therefore, that the rations fed were all similar in their capacity to promote gain in liveweight. In other words, this method of analysis revealed that no significant weight differences resulted from supplementing the basal ration with equivalent amounts of calcium as it occurred in the supplements studied. This method further indicated that no improvement in average daily gains can be expected by adding a calcium supplement to the check ration composed of corn and trinity mixture.

TABLE XXIX

Average Daily Gain in Liveweight by Periods (lbs.)

	Lot No.	Distinguishing Features of Ration	First 30 days	Second 30 days	Remainder of Exp. 10-17.5 days
Series I	I	Check	1.79	1.60	2.58
	III	Limestone	1.68	1.59	1.99
	V	Bonemeal	1.67	1.69	1.83
	VII	Dicapho	1.70	1.70	1.88
Series II	II	Check	1.71	1.62	1.95
	IV	Limestone	1.79	1.83	1.90
	VI	Bonemeal	1.76	1.68	2.02
	VIII	Dicapho	1.89	1.60	1.98

Table XXIX presents the average daily gains by 30-day periods. It will be noticed in this table that all lots excepting Lots IV, V, and VII made larger average daily gains during the first 30-day period than during the second 30-day period. The lower average daily gains during the second 30-day period were caused, in all probability, by the light attack of influenza which affected all groups during this period. As may be gathered from the data, however, all pigs throughout the experiment made excellent daily gains in liveweight.

2. Feed Consumption per 100 Pounds Gain in Liveweight

The data in Table XXX show that the pigs in Lot I required the largest amount of feed per 100 pounds gain in liveweight, while those in Lot IV required the least feed, the difference amounting to 24.92 pounds. The greatest mean difference was 11.41 pounds, which occurred between the lots receiving the check ration and the lots receiving the Dicapho ration.

TABLE XXX

Feed Consumption per 100 Pounds Gain (lbs.)

Distinguishing feature of ration	Check		Limestone		Bonemeal		Dicapho	
	Lot I	Lot II	Lot III	Lot IV	Lot V	Lot VI	Lot VII	Lot VIII
Series I	396.31		391.26		389.22		381.15	
Series II		386.95		371.39		385:88		379:29
Mean	391.63		381.32		387.55		380.22	

The question naturally arises as to the significance of the greatest mean difference, amounting to 11.41. When the limited amount of data was subjected to Fisher's Method (27) of analysis of variance, the standard deviation of the mean difference was 5.66 pounds. Inasmuch as the mean difference should be at least 4.3 times larger than its standard deviation to be significant when there are but two degrees of freedom, this difference is no more than one might expect between the means of lots of 10 pigs, each lot receiving the same treatment. Since the greatest mean difference is non-significant the smaller differences would not be significant.

TABLE XXXI

Average Daily Feed Consumption by Periods (lbs.)

	Lot No.	Distinguishing Features of Ration	First 30 days	Second 30 days	Remainder of Exp. 10-17.5 days
Series I	I	Check	6.37	7.35	9.32
	III	Limestone	6.03	7.04	8.11
	V	Bonemeal	5.90	7.06	8.22
	VII	Dicapho	5.78	7.15	8.35
Series II	II	Check	5.61	7.14	8.30
	IV	Limestone	5.91	7.33	8.55
	VI	Bonemeal	5.92	7.26	9.30
	VIII	Dicapho	6.02	7.05	8.75

Referring to Table XXXI, the average daily feed consumption increased as the experiment progressed, and the feed intake daily ranged from 5.61 pounds in Lot II, in the first 30-day period, to 9.32 pounds in Lot I in the last period of the experiment. The pigs in Lot I not only had the highest average daily feed consumption per pig, but they also produced the largest daily gains made in any period during the experiment -- 2.58 pounds per pig, as tabulated in Table XXIX.

I. Discussion of Experimental Results

Experimental data have been collected on average daily gains in liveweight and feed consumption per 100 pounds gain in weight. In Series I the greatest difference in average daily gains per pig (between lots) was 6.08 pounds, while in Series II the difference was 0.1 pound. The daily gains made in Series II checked with those of Series I so that the largest difference in average daily gains, between the lots, was 0.1 pound. According to Fisher's Method for analysis of variance (27), a difference of 0.1 pound may be expected, due to individuality in pigs receiving the same treatment.

Data on feed consumption per 100 pounds gain in weight show that the largest mean difference between the lots receiving different rations was 11.41 pounds. The standard deviation of this mean difference is 5.66 pounds. The mean difference should be at least 4.3 times larger than its standard deviation (when there are but two degrees of freedom) to be significant. It is evident therefore, that this difference is not significant. These results, in part, form the basis of conclusions made later.

SUMMARY

When equivalent amounts of calcium, as present in ground limestone, steamed bone meal, and Dicapho, were fed as supplements at low and high levels of intake to a low calcium basal ration, the retention of calcium and phosphorus by all pigs so fed was similar, with one exception. On a high level of calcium supplementation one pig, which received the limestone supplement, had a less favorable calcium and phosphorus retention than the pigs which received the bone meal and Dicapho supplements. When the amount of phosphorus in the limestone supplemented ration was increased by the use of a neutral mixture of mono- and di-sodium phosphate to an amount similar to that found in the bone meal ration, this pig's retention improved. Apparently, hog rations having a Ca:P ratio as wide as 2.13:1 and at the same time supplying minimum quantities of antirachitic are unsatisfactory for best results.

Bone analyses were made on the femurs and humeri of one group of four pigs. The data collected indicate very small differences in the composition of the bones of the pigs which received ground limestone, steamed bone meal, and Dicapho. The femurs and humeri of a check pig which was fed a low-calcium basal ration, were low in ash, calcium, and phosphorus content.

A feed lot experiment was conducted involving the use of 80 uniform feeder pigs, averaging 88 pounds in weight. These pigs were divided into eight lots, four of which formed Series

I, and the remaining four, Series II. Series II served as a check on Series I.. All lots were fed free-choice style from self-feeders. One lot in each series was fed a finely ground check ration composed of corn, tankage, linseed oilmeal, alfalfa meal, and salt. The remaining three lots in each series were fed the check ration supplemented with equivalent amounts of calcium as present in ground limestone, bone meal, and Dicapho respectively. As judged by gains in weight and feed consumed per 100 pounds gain, the three calcium supplements under consideration were utilized by the pigs with equal efficiency. A calcium and phosphorus metabolism trial, which was conducted at two different times on representative barrows taken from Series II, confirm these results.

GENERAL CONCLUSION

As outlined in the Statement of Problem, the object of these experiments was to determine whether or not, under certain conditions, the difference in the metabolic utilization of limestone, bone meal, or Dicapho (as calcium supplements to hog rations) was great enough to justify the difference in cost to the farmer.

A knowledge of the comparative costs of the three calcium supplements considered, and a knowledge of their comparative values in feeding (as observed in the foregoing experiments), lead to the following conclusions.

The data presented in this thesis show that when a calcium supplement is necessary in the ration, calcium, whether it is in the form of limestone, bone meal, or Dicapho, is utilized by the pig with equal efficiency. Therefore, from a practical point of view, when the basal ration is low in both calcium and phosphorus, it is advisable to use bone meal as the supplement, for it supplies both calcium and phosphorus in suitable proportions, and it is less expensive than Dicapho. If the ration is appreciably higher in phosphorus than in calcium, it is then advisable to use ground limestone, since in appropriate additions it would supply the necessary amount of calcium to secure the proper calcium-phosphorus relationship.

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